Curtin University Sustainability Policy Institute

Bhutan's Development Nexus: Economic Analysis of the Complex Interplay between Carbon Neutrality, Gross National Happiness and Economic Growth

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Doctor of Philosophy
of
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Author's declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Human Ethics: The semi-structured interviews presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number # HRE2016-0391.

Dorji Yangka

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Statement of contributors

All of the written materials submitted as part of this PhD by Hybrid Publication were conceived and coordinated by Dorji Yangka. I also undertook data collection and analysis, and the majority of the writing for each publication.

Signed, detailed statements from each co-author relating to each publication are provided as appendices at the back of this thesis (Appendix B).

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Dorji Yangka, PhD Candidate

Professor Peter Newman, Principal Supervisor

Date: July 2019

Abstract

Stabilising and reducing greenhouse gas (GHG) emissions, as required by the Paris Agreement, is now the global climate objective and countries around the world have been grappling with how best to achieve this. At the same time the Sustainable Development Goals (SDG's), which were adopted globally in 2015, will mean significantly increasing economic development for many nations, especially in emerging economies. Such countries will need to seek low- or net zero emissions growth alongside their other development goals. This thesis seeks to examine the nexus between such goals and apply it to the emerging economy of Bhutan.

Climate change mitigation and adaptation is being adopted with varying degrees of ambition between nation-states. At one end of the spectrum lies a group of countries that have pledged to pursue carbon neutrality. Bhutan, a tiny developing nation in the eastern Himalaya, best known for its Gross National Happiness (GNH)-based development strategy, is among these nations that made a pledge at the 15th session of the Conference of Parties held at Copenhagen in 2009. It is also one of very few countries to have achieved this goal. To maintain its carbon neutral (CN) goal, however, Bhutan will need to limit its CO_2 equivalent emissions below its CN budget of 6.3 million tonnes, which is provided by their extensive forest carbon sink.

The aim of this thesis is to explore if and how Bhutan can maintain its CN pledge, in light of its growing economy and increasing GHGs, while continuing its pursuit of its GNH strategy as part of its development commitments. The thesis attempts to resolve the nexus between GHG, GNH and GDP by highlighting the subtleties in understanding, defining and achieving carbon neutrality in Bhutan and to show how other emerging nations can learn from such analysis.

The thesis includes five publications, supported by an exegesis. The research uses both qualitative and quantitative approaches. An extensive literature review was undertaken, which includes a large amount of secondary data. This is complemented by primary data that was collected through interviews with key stakeholders inside Bhutan on their understanding of how Bhutan is faring in terms of maintaining their ambitious climate goal. This analysis reveals a degree of confidence and optimism, though also potential complacency, about maintaining the country's CN goal into the

future, which could be cause for concern. There were also divergent viewpoints on factors that could hinder or facilitate Bhutan's CN goal.

Information gathered from the interviews also shows that the resource endowments, in terms of forest cover and hydropower, along with its unique internal determinants such as pro-environmental Constitution and GNH strategy, can help to sustain Bhutan's CN goal. Similarly, carbon neutrality can also support the GNH strategy, as well as Bhutan's middle-income GDP aspiration.

A Bhutan–LEAP (Long-range Energy Alternatives Planning) energy model was developed to quantitatively investigate future energy–economic pathways that may be required to sustain the ambitious pledge, which has a planning horizon from 2014 to 2050. It also examines the presence of the Environmental Kuznets Curve (EKC) hypothesis using regression analysis to investigate the impact of economic growth on the carbon intensity of human wellbeing for Bhutan.

The results from the Bhutan–LEAP model illustrate the possibility of breaching the pledge as early as 2037 under high economic growth, which is consistent with Bhutan's middle-income aspiration. This is also seen under the Business-As-Usual (BAU) scenario. Containing the emissions level below the sink capacity would require a more efficient, low carbon industrial production process and a massive uptake of electrified transport in Bhutan, which would result in significant costs for the government. Therefore, sustaining the CN pledge will be more challenging in the coming decades as Bhutan develops its economy from a low base. Nonetheless, some mitigation measures come with co-benefits, for example, replacing fossil energy and fuelwood in households potentially meets Goal 7 of the United Nations SDGs, and also reduces the abatement cost at an economy-wide level. The industrial and transport changes which will create more efficient production based on hydro power also shows cost savings under some scenarios while reducing emissions and imports of oil products. The need for more electrified energy systems points towards the increasing role of hydropower though significant potential to expand this exists.

Further investigation of the EKC reveals that Bhutan's data partly support both the Treadmill of Production theory and the Modernisation theory, the two dominant environmental impact theories currently referred to in literature about the nexus over

growth. Results reveal evidence of relative decoupling along the development trajectory over the past 33 years. Furthermore, it seems that population factors need not be a cause for concern in relation to the carbon intensity of human wellbeing in Bhutan, though changes in priorities for industry and transport remain a major concern. Overall, this thesis exposes the complex interplay between the three core goals of Bhutan and the options for their integration. Their combination demonstrates how Bhutan's unique development pathway can contribute to the broader sustainability discourse and establishes a model for how the development nexus can be resolved for emerging economies.

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Dedication

I would like to dedicate this thesis to my father, my late Mother and to all my teachers who have shaped my academic journey.

Publications submitted as part of this thesis

Below is a bibliographic list of the publications representing the body of research for this PhD thesis.

Publication 1:

Yangka, D., Newman, P., Rauland, V. & Devereux, P. (2018). Sustainability in an emerging nation: The Bhutan case study. *Sustainability, 10*(5), 1622.

Publication 2:

Yangka, D., Rauland, V. & Newman, P. (2018). Carbon neutral policy in action: The case of Bhutan. *Climate Policy*, 1–16.

Publication 3:

Yangka, D., Newman, P., (2019). Happiness, environment and wealth: What can Bhutan show us about resolving the nexus? *Modern Economy* (accepted).

Publication 4:

Yangka, D. & Newman, P. (2018). Bhutan: Can the 1.5 °C agenda be integrated with growth in wealth and happiness? *Urban Planning, 3*(2), 94–112. doi: 10.17645/up.v3i2.1250

Publication 5:

Yangka, D., Rauland, V. & Newman, P., (2018). Carbon neutral Bhutan: Sustaining carbon neutral under growth pressures (submitted).

Other relevant publications (not submitted as part of this thesis)

Publication 1:

Newman, P., Hargroves, K. C., Davies-Slate, S., Conley, D., Verschuer, M., Mouritz, M. & Yangka, D. (2019). The Trackless Tram: Is it the Transit and City Shaping Catalyst we have been waiting for? *Journal of Transportation Technologies, 9*, 31-55. doi:10.4236/jtts.2019.91003

Publication 2:

Dorji Yangka, 'Environmental Intensity of Human Wellbeing in Bhutan: Evidence from regression analysis', the IAFOR International Conference on Sustainability, Energy and Environment, Hawaii, January 4–6, 2018.

Publication 3:

Dorji Yangka, 'Energy Policy to achieve simultaneous goals in carbon neutral, GDP and GNH: the Bhutan story', World Renewable Energy Congress XVI (International Conference), Murdoch University, Western Australia, February 5–9, 2017.

Publication 4:

Yangka, D., & Diesendorf, M. (2016). Modeling the benefits of electric cooking in Bhutan: A long term perspective. *Renewable and Sustainable Energy Reviews, 59*, 494-503. doi:10.1016/j.rser.2015.12.265

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Chapter 1 Introduction

The global community is constantly searching for nations that can demonstrate sustainability (Givens, 2014; Lamb, 2016; Steinberger, Roberts, Peters, & Baiocchi, 2012), even though the burgeoning problems that human society faces today are complex and cross over disciplinary boundaries (Cumming, 2014). Climate change is one such problem as it not only crosses over local, regional and national boundaries, but warrants transcending conventional approaches to development issues. To that extent it is even dubbed a ‘social mess’ and a ‘super wicked problem’ (Lazarus, 2009; Levin, Cashore, Bernstein, & Auld, 2012). Despite this, the global community is moving forward in an effort to mitigate it (IPCC, 2018; UNFCCC, 2016; United Nations, 1998), and acknowledges the dual relationship between climate change and sustainable development (Halsnæs et al., 2007; IPCC, 2014; United Nations, 2015). Recognising these sustainability issues, the global community committed to two ambitious goals in 2015: the climate target of 1.5° to 2^0 C, adopted at the Paris Agreement during the 21st session of the Conference of Parties (UNFCCC, 2016), and the United Nations 17 global Sustainable Development Goals (SDGs) (United Nations, 2015). This thesis examines how these two historic agreements, in conjunction with Bhutan’s Gross National Happiness Index, could assist the development trajectory of Bhutan and other emerging nations. The Introduction sets out the core concepts of the thesis, the Bhutan context and the aims of the research.

1.1 Sustainable development

The meaning of sustainable development was first set out by the United Nations in 1987 but remains a contested concept (Giddings, Hopwood, & O'Brien, 2002; Hedlund-de Witt, 2014; Hopwood, Mellor, & O'Brien, 2005; Shahadu, 2016; Walker, 2017). The UN definition was that “sustainable development is development that meets the needs of the present without compromising the ability of the future generations to meet their own needs.” (WCED, 1987). It requires integrating social, economic and environmental goals that are accepted as the challenge for humanity in the 21st century (Newton & Newman, 2015). To this end, Holling (2001) posits the ‘Theory of Panarchy’ to capture the dimensions of sustainability. The global effort towards mainstreaming sustainable development moved forward inexorably through governments, business and communities, culminating in the Sustainable Development

Goals (SDGs) which were developed by the United Nations (UN) and signed by all nations in September 2015 (United Nations, 2015). The SDGs were the successor to the Millennium Development Goals (MDG), which were adopted in 2000 and ended in 2015 and were mainly aimed at encouraging developing countries to reduce their socio-economic frailties (Sachs, 2012). The SDGs were found to be more integrated and broader than the MDGs, and applied to both emerging and developed economies, and provided policy integration across sectors (Blanc, 2015; Halisçelik & Soytas, 2018). The SDGs envision a sustainable human society by 2030 through its 17 goals, which include providing access to modern energy services, reducing poverty, eliminating hunger, safeguarding the natural ecosystem, and taking action on climate change, among others. The link between SDG's and Gross National Happiness in Bhutan will be explored further below, however, the primary focus of this thesis is around carbon reduction and climate change, which has been given not only an SDG (number 13), but is a specific development goal of Bhutan, and has an extensive international agreement that has been developed over the past 30 years through the UN.

1.2 Climate change

The effect of Carbon Dioxide (CO_2) emissions on the global temperature rise was demonstrated scientifically many decades ago (Callendar, 1938; Revelle & Suess, 1957), long before the UN adopted it as a major global issue. The Intergovernmental Panel on Climate Change (IPCC) was formed in 1988 under the joint signatory of the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) to provide scientific information on, and impact assessment of, climate change and provide strategic responses to mitigate climate change (UNEP & WMO, 1989). This was then followed by the establishment of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 (United Nations, 1992), which had a mandate to act as the global institution to stabilise the greenhouse gas concentration in the atmosphere, the primary driver of climate change. Under the UNFCCC, member countries joined the Conference of Parties (COP), which was formed as the main body, mandated to facilitate and review the effective implementation of the objectives of the UNFCCC (United Nations, 1992). The first session of COP was held in Berlin in March 1995 (UNFCCC, 1995). Thereafter, global climate change negotiations were held annually. At one of the key COPs, held in Kyoto in 1997, quantified emissions reduction commitments were made (United Nations, 1998), resulting in the ‘Kyoto Protocol, a major international policy to curb emissions level (Goldemberg & Prado, 2010). There have been mixed public and political perceptions about the level of emissions reduction achieved since then (Schiermeier, 2012). However, Grunewald and Martinez-Zarzoso (2015) argue that the Kyoto Protocol has had an effect on emissions reduction, although not significant. At COP15, held in Copenhagen in 2009 (UNFCCC, 2009), expectations and ambitions were high for an agreement on what would replace the Kyoto Protocol However, feelings were mixed about what ultimately eventuated. On the one hand, COP15 went down in the history of global climate negotiations as a disaster for failing to agree on emissions reduction; on the other hand, it was the beginning of an ambitious journey for a handful of countries including Bhutan, which pledged for carbon neutrality, an ambitious climate commitment.

The Paris Agreement (UNFCCC, 2016) now targets 1.5° to 2^0 C global temperature rise, where participating countries submit their emission reduction measures, referred to as the Nationally Determined Contribution (NDC). On the imperatives for emission reduction, the IPCC, in its Fifth Assessment Report (AR5), clearly stated that “Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions.” (IPCC, 2014). The need for net zero emissions to be reached in order for climate stabilisation is widely acknowledged (Bataille, Waisman, Colombier, Segafredo, & Williams, 2016; Fay et al., 2015; Matthews & Caldeira, 2008; Matthews, Zickfeld, Knutti, & Allen, 2018). SDG 13 and the Paris Agreement suggest that there is momentum towards fundamental reappraisal of development models, though there are clear issues between present growth trends, policies and institutions committed to achieving other goals. This nexus requires new approaches to development that will be examined and illustrated in this case of Bhutan. This requires new thinking about the entire socio-technical system as raised by Cumming (2014) and Quental, Lourenço, and da Silva (2011) who have argued for an integrated, synergistic approach– the need to reconcile various disciplinary perspectives that hinder achieving truly sustainable endeavours.

Is the world on track to achieve these noble goals outlined in the SDG and the Paris Agreement? In a study in 2008, Pillarisetti and van den Bergh (2008) found that only

29 out of 119 countries were sustainable based on the index generated jointly using three sustainability indices (Genuine saving, Ecological footprint and Environmental Sustainability Index). While there are differing viewpoints on the effectiveness of the Paris Agreement for a pathway towards climate stabilisation (see the special issue in the journal of *Climate Policy,* (Viñuales, Depledge, Reiner, & Lees, 2017), the UN has shown in their 9th Emissions Gap Report (UNEP, 2018) that – based on the current national pledges – the world is still *not* on track for meeting the emission reductions targets to limit emissions even to 2°C.

The International Energy Agency (IEA, 2018) revealed that global CO_2 emissions have increased from 15.4 Mega tonnes (Mt) in 1973 to 32.3 Mt in 2016, with coal, oil and gas still contributing to 66% of the final energy consumption. UNEP (2018) also warned that global emissions may not peak by 2020, as initially expected, after observing that they increased in 2017 after stabilising for a brief period from 2014 to 2016. Ribas, Lucena, and Schaeffer (2017) discussed the incompatibility of providing adequate energy access for the wellbeing of the entire global population and stabilising the global climate, even at 2°C. Zang, Zou, Song, Wang, and Fu (2018) demonstrated that the rate of convergence of the per capita emissions at the global level during 2003 to 2015 was lower than that for emissions per unit of GDP. Furthermore, there are different perspectives at play at this critical juncture. The grim future prediction is that economic growth itself is destabilising the climate and that technological fixes are insufficient (Northrop, 2017), thus leading to the need for a sufficiency and degrowth strategy (Andreoni & Galmarini, 2014; Verma, 2017). Others argue for a radical socio-technical transformation (He, Teng, & Qi, 2015), while some see hope in technological advancement and human ingenuity to create resilient human habitats for a rapidly urbanising world (Newman, Beatley, & Boyer, 2017; UN-Habitat, 2016). Perhaps the one thing that all the commentators see is the need for low carbon development pathways to be on the agenda for the future (Bataille, Waisman, Colombier, Segafredo, Williams, et al., 2016; Mulugetta & Urban, 2010; Nishioka, 2016; Reilly, 2013).

1.3 Carbon neutrality and sustainable development

In the midst of these divergent and convergent viewpoints, there are nation-states that have voluntarily committed to carbon neutral policy. In the lead-up to the Copenhagen Accord during COP15, nine nations pledged to become carbon neutral (Flagg, 2015), which increased to 15 during COP23 in Bonn (Carbon Neutrality Coalition, 2017). Recently it was reported that the number has increased to 19 countries[1].

Townshend et al. (2013) compliment the unilateral pledges made by nation-states to enhance international climate negotiation, however the transition to a low carbon and sustainable economy is highlighted as a major transformation that can be compared to the industrial revolution (Messner, 2015), suggesting the need for enormous resource requirements to achieve and sustain it. The problem is that this requires balancing such requirements with the needs for achieving other development goals. The Low Carbon Society initiative, a joint undertaking by Japan and the United Kingdom in 2006 that aims to stabilise climate change through low carbon visions (Nishioka, 2016; Reilly, 2013; Skea & Nishioka, 2008), reflected that pursuing low carbon development should be compatible with sustainability principles. This complements Lamb (2016) claim that "Low-carbon development is consequently a normative definition, requiring an assumption of fairness, but it is nonetheless grounded in the science of cumulative emissions budgets" (p. 4). He et al. (2015) argue for 'new climate economics' that can establish a win-win situation to address sustainable development and climate change mitigation. These authors suggest that climate change mitigation, the obvious reason for a low carbon pathway, should also place sustainable development at its core – highlighting the complexity, and thus the need, for a nexus approach to resolve conflicting goals.

Ambitious long-term emissions reduction targets are required to preserve the glaciers globally (Marzeion, Kaser, Maussion, & Champollion, 2018). The 1.5°C global warming agenda is found to be crucial to save the glaciers of Asia (Kraaijenbrink, Bierkens, Lutz, & Immerzeel, 2017). This is also important for Bhutan whose economy is dependent on the hydropower sector and agriculture (Bisht, 2013; Hoy, Katel, Thapa, Dendup, & Matschullat, 2015). Bhutan is the only nation that pledged, and actually achieved, carbon neutrality during COP15 (GNHC, 2011). Despite being a low-income developing nation and being at the periphery of the global political economy, it has bold ambitions – pursuing both its CN pledge and its unique Gross National Happiness (GNH) strategy (see Section 1.4.1). This presents itself as a worthy

[1] See publication 2

area for research in which to examine the challenges of pursuing ambitious climate policy, while also enhancing socio-economic goals.

The next section provides a brief background on Bhutan and its socio-economic development strategy and CN policy. Further information on Bhutan is also outlined in each of the five publications presented in the Appendices.

1.4 Bhutan: Development strategy and carbon neutral policy

Bhutan is a tiny land-locked country located in the fragile Himalayan ecosystem, sandwiched between China and India (see Figure *1*). Bhutan has a population of 735,553 as of 2017 (NSB, 2018) and a per capita gross domestic product (GDP) of US$2879 in 2016 (NSB, 2017). The country is made up of vastly rugged terrain with swift-flowing rivers, and it lies in three climate zones: alpine, temperate and subtropical, with an altitude that varies between 150 metres to more than 7500 metres above sea level (NEC, 2016; NSB, 2015). The alpine zone remains covered by snow throughout the year. The inner valleys where the majority of human settlement is based (see Figure *2*), falls in the temperate climate zone (NSB, 2015).

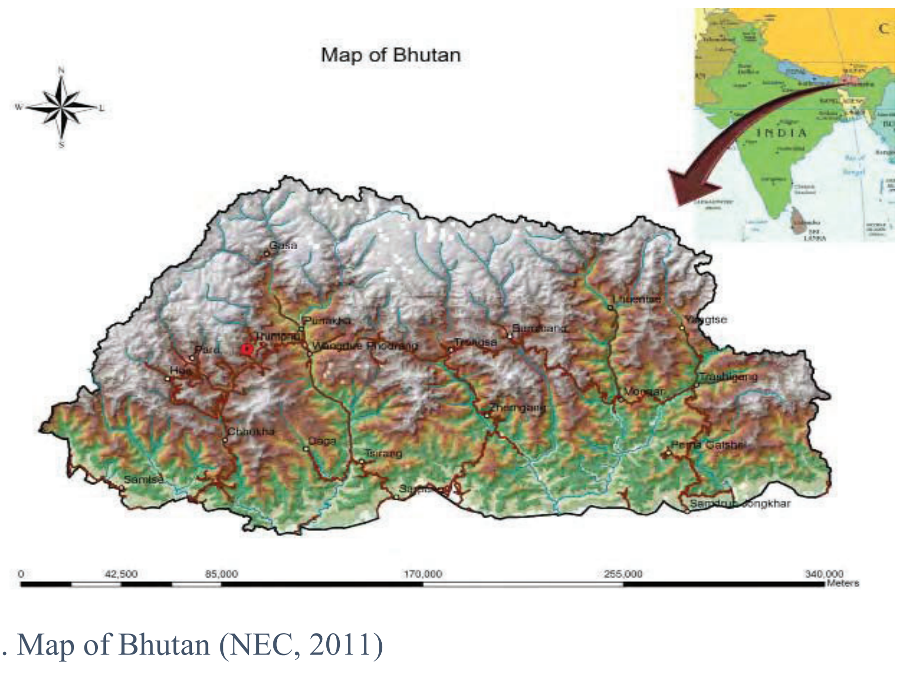

Figure 1. Map of Bhutan (NEC, 2011)

Figure 2. Human settlement area in inner valley (source: Author)

1.4.1 Gross National Happiness – Bhutan's guiding development paradigm

Bhutan is unique for its pursuit of Gross National Happiness (GNH), a development strategy, which was enunciated by the Fourth King of Bhutan in the early 1970s (CBS, 2012, 2016; RGoB, 1999). GNH is a development paradigm concerned with holistic development rather than pure economic development (Allison, 2012; Givel, 2015; Thinley, 2005). GNH is increasingly recognised globally and it is linked with sustainable development (Allison, 2012; Brooks, 2013; RGoB, 2012b). It is measured through its GNH index, which comprises four pillars, nine domains, 33 indicators and 124 variables (CBS, 2012) and the GNH index is calculated based on nationwide surveys, which were conducted in 2010 and 2015 (CBS, 2012, 2016).

To ensure policy relevance of the GNH philosophy to Bhutan's development planning, a policy screening tool founded on GNH variables was introduced in 2008 at the national level and a GNH checklist at the sub-national level (CBS, 2008, 2016; Schroeder, K., 2015). Furthermore, the GNH index, obtained through periodic nationwide surveys, also informs other policymaking in Bhutan (Ura, 2015). Since then, Bhutan has adopted a middle path development paradigm (NEC, 1994, 1998; Rinzin, 2006) – that is, the long-term development goal for Bhutan is to balance the material and non-material needs of both current and future Bhutanese (NEC, 1998). In this regard, Ura (2015) contends that GNH has provided a normative orientation for both the state and the society to do things differently, which has led to a balance between tradition and modernisation, environment and economic growth. This thesis attempts to test this conjecture through quantitative research design and economic modelling.

1.4.2 Combining goals and aspirations

Bhutan is cognisant of the challenges posed by sustainable development, given their aspiration for economic self-reliance and creation of employment emphasised in their Economic Development Policy (RGoB, 2010b, 2016), and now, the need to sustain their carbon neutral goal. The sustainability challenge for Bhutan is to answer the critical question of, "How do we meet the social and economic needs of our people while still conserving the natural environment?" (NEC, 1998, p. 12). This resonates with a reflection from Newman (2015) "Sustainability is the challenge of our century: to do economic development in a way that reduces environmental impact whilst improving social needs" (p. 140). This is reflective of the complex issues at the global level, especially for emerging nations where economic development has powerful political dimensions as most people in poverty can now see through global communications what they do not have. Gonzalez et al. (2015) suggest that there is a significant challenge and opportunity to address social, environmental and economic issues in parallel. Yet sustainability discourse itself is highly contested, spanning disparate disciplinary approaches (Giddings et al., 2002; Hopwood et al., 2005), and being identified as a wicked and messy problem (Frame, 2008); thus the need for an integrated approach (Quental et al., 2011). This thesis takes the sustainability question raised by Bhutan as the first *point of ignition* for this PhD research.

1.4.3 Bhutan and socio-economic development

While Bhutan pursues GNH strategy, it has a long way to go in providing basic infrastructure and institutional capacity because of its rugged and harsh landscape, and limited human and financial resources. Low productivity has been observed both in the agriculture sector (Mehta, 2012) as well as in the overall economy (Mitra, Carrington, & Baluga, 2014). Bhutan's development is reliant on natural resources such as agriculture, forestry and hydropower, which are climate sensitive (Hoy et al., 2015; NEC, 2011, 2016). Besides having vast forest cover, Bhutan is blessed with swift-flowing rivers which are harnessed for hydropower (see Figure *3*).

Figure 3. Forest cover and swift flowing river (source: Gawa Jamtsho with permission)

In fact, export of hydroelectricity remains a key source of revenue for national development (DRC, 2018). The long-term economic goal of Bhutan is self-reliance, which was stated as an imperative necessity in its long-term vision (RGoB, 1999), and continues to be a national objective with the added inclusion of green growth strategy in its 11th five-year plan (RGoB, 2013) and its economic development policy (RGoB, 2010b, 2016). In keeping with this, Bhutan pushes towards becoming a middle-income country by 2023,[2] and it can be expected that there could be significant reduction of external aids and/or the country no longer eligible to accept them. Conversely, Bhutan emphasised that to remain carbon neutral, international support is required to carry out emissions reduction plans (NEC, 2011). It is thus reasonable to assume that graduation from low-income status and insufficient domestic revenue could pose a critical challenge for Bhutan to finance its CN goal.

[2] Over the course of my PhD journey, Bhutan's expected graduation towards middle-income country shifted from 2018 to 2021 and now to 2023. The latest deadline is outlined in an on-line newspaper the Kuensel issue of 2 June 2018: http://www.kuenselonline.com/bhutan-proposes-to-graduate-from-ldc-in-2023/

1.4.4 Carbon neutrality and Bhutan

As mentioned, Bhutan declared to the global community in 2009 at COP15, that it will remain CN in perpetuity (RGoB, 2010a). This pledge was reiterated during the Paris Agreement at COP21 in 2015 (RGoB, 2015). Unlike other countries that have pledged for carbon neutrality, Bhutan is the only nation that is not only CN, but is in fact carbon negative at present, with an estimated CN budget of 6.3 million tonnes (RGoB, 2015) against estimated CO_2 equivalent emissions of 2.4 million tonnes in 2014 (see Publications 4 and 5). The CN goal sits alongside its goal to continue its home-grown GNH strategy (CBS, 2012, 2016; Thinley, 2005) and its aspiration to be a middle-income country by 2023. Bhutan speculates that "sustaining the country's commitment to remain carbon neutral in the face of a growing economy is a serious challenge" (GNHC, 2011, p. 55). This is a legitimate concern for a tiny developing nation and thus forms the second *ignition point* for this PhD research.

The critical task of Bhutan's Low Carbon Strategy (NEC, 2012) is to balance economic development and sufficient and affordable energy resources, alongside conserving local environment and climate change mitigation. However, the tricky part and the challenging task is that energy for socio-economic activities is a legitimate concern shared globally (Nilsson, Lucas, & Yoshida, 2013). For Bhutan, energy-consuming sectors notably the transport and industry were the key emitters of GHG (NEC, 2011). In light of this, the Climate Action Tracker (2015) cautioned Bhutan that in the long-run, rising emissions from energy-consuming sectors may not be fully offsets by it's forest carbon sink. Thus, the question around how Bhutan will sustain its carbon neutral goal in the long-run needs to be addressed and it forms the third *ignition point* and crux of this PhD research.

1.5 Research aim, scope and limitations

The aim of this thesis is to explore how Bhutan can limit its carbon dioxide equivalent (CO_2eq) emissions below its carbon neutral budget of 6.3 million tonnes, while its economy grows from a low base. In doing so, it examines the long-term possibility for Bhutan to retain CN status, while also meeting the SDGs and addressing the other economic development issues. This thesis therefore outlines the subtleties in understanding, defining, achieving and retaining CN in Bhutan as it aspires to grow its economy and further its GNH. Furthermore, considering the need to balance economic growth and environmental quality, the thesis also examines the Environmental Kuznets Curve (EKC) hypothesis to investigate the nexus between human wellbeing, environment and economic growth (discussed in Chapter 2 and Publications 1, 3 and 4). These then direct the thesis into the area of sustainable development, especially for emerging nations. This research argues that sustaining carbon neutral goal will require commitment to low emission socio-economic structures founded on sustainable energy systems (SES). The main focus is on the energy-consuming economic sectors in Bhutan, considering that energy production and consumption are key sources of GHG emissions (IPCC, 2014; Rogelj, Luderer, et al., 2015; Stern, P. C., Sovacool, & Dietz, 2016), while being a prerequisite for human need and economic growth (Fankhauser & Jotzo, 2018; Nilsson et al., 2012; Ribas et al., 2017; UNDP, 2002; United Nations, 2015).

This thesis will not examine all the multi-disciplinary approaches needed for the sustainability transition but will focus on how economic modelling of policy options can help resolve the nexus between climate change and various growth pressures.

The main research question is therefore:

> What will it take for Bhutan to remain carbon neutral, as well as increase its GNH, as the economy grows?

This central question warrants putting the case of Bhutan into the contemporary discourse of climate policy and the environmental impact of economic growth, which leads to a series of sub-questions:

1. What is carbon neutrality and Gross National Happiness (GNH), and how do they relate to the global agenda?

2. How is Bhutan currently meeting its goals and what is Bhutan's development trajectory?

3. What are the challenges for Bhutan to sustain its carbon neutral pledge?

4. What planning and policy options can assist Bhutan in sustaining the carbon neutral pledge, while increasing GNH and gross domestic product (GDP)?

1.5.1 Limitations

Given the broad nature of this research, there are several areas and issues that are not able to be elaborated upon within this thesis, and thus are deemed 'out of scope'. For example, the existing carbon sink capacity forms the limit to carbon emissions, but assessing how to calculate the emissions, or how to maintain or enhance the carbon sink through forestry and other rural carbon sequestration, remains out of the scope of this thesis. Bhutan is very much focused on environmental protection and forest conservation with its constitutional requirement to conserve a minimum of 60% forest cover for all time, which stands at 71% as of 2017 (MoAF, 2017). Thus, it is a reasonable assumption that its carbon sink will remain intact.

The research focuses on an energy system that includes most types of energy sources and technologies employed, both on the supply side and on the demand side. The demand side includes all economic sectors, such as transport, industry and buildings, where energy is consumed (see Chapter 3, Research design and method). It is to be noted that waste-to-energy and emissions from the use of diesel-powered land-tilling in the agriculture sector, were also included in the energy system boundary. Considering the research focus on the energy system, any low-emission strategies for waste management, farming and agricultural activities that do not directly involve either energy production or consumption were not included. However, the baseline emissions from waste, farming and agriculture, were taken into account while developing the long-term energy-economy model for Bhutan (see Publications 4 and 5). Acknowledging that climate policy is broadly categorised into mitigation and adaptation (Halsnæs et al., 2007; IPCC, 2014) (discussed further in Section 2.1.1), this thesis focuses on the mitigation policy and territorial GHG emissions in line with the existing CN pledge of Bhutan.

1.5.2 Significance

At present there are very limited studies on Bhutan's low carbon pursuit and long-term energy policy modelling (Shrestha, Ahmed, Suphachalasai, & Lasco, 2013; Yangka & Diesendorf, 2016), nor any specific studies related to carbon neutrality. There has also been only limited research on other specific energy studies in Bhutan, such as household energy (Lhendup, Lhundup, & Wangchuk, 2010; Rahut, Ali, & Behera, 2017; Rahut, Behera, & Ali, 2016; Rahut, Mottaleb, Ali, & Aryal, 2017), energy efficiency (Jamtsho, 2015) and on topics related to renewable energy, rural electrification and off-grid energy systems (Dorji, Urmee, & Jennings, 2012; Young, Mill, & Wall, 2007). Peer-reviewed journal papers related to how Bhutan will maintain carbon neutrality and GNH into the future do not exist.

To assess the contribution and significance of any research, Sovacool et al. (2015) and Stern, P. C. et al. (2016) asked two questions relating to the immediate practical implications and the contribution to fundamental knowledge. This study attempts to make significant contributions in both areas.

The research models various growth scenarios or plausible socio-economic pathways, including the different types of energy technologies that may underpin these scenarios, to better understand if, and how, Bhutan can remain within its CN budget. It is expected that this new knowledge will have immediate practical implications to help inform policymakers in Bhutan about the types of energy policies and technological shifts that may be required, and the cost of emissions mitigation leading to practical outcomes. This can form the basis for formulating programmatic action plans to garner international climate finance, as well as to assist in updating Bhutan's NDC's under the Paris Agreement.

A fundamental contribution of this thesis is its ability to bring together the data on Bhutan in a way that contributes to the debate about the nature of sustainable development, especially in a rapidly growing emerging economy. A regression analysis investigates the impact of economic growth on the carbon intensity of human wellbeing in Bhutan. This formally places Bhutan's story into the burgeoning debate on the environmental impact of economic growth. It contributes to the understanding of the complexity of resolving the two dominant environmental impact theories: Ecological Modernisation theory and the Treadmill of Production theory. It paints a picture of a complex development trajectory far beyond what Bhutan conjectures at present. In-depth interviews with key people in Bhutan's public and private sectors (both decision-makers and government officials responsible for implementing policies) provided valuable insights and a glimpse into the inside story of a developing country, exposing some interesting challenges and unique enablers that a low-income developing country might face in upholding carbon neutrality. To some extent, the stakeholders in Bhutan are discovering how to integrate the nexus between the three goals, but many issues remain unresolved and difficult; however, this research demonstrates how the nexus can be resolved between these three fundamental goals that are at the core of sustainable development.

Thus, this research fills an important gap in the literature, by providing key insights into the complex challenges faced by a tiny, developing nation in trying to maintain its holistic development concept (i.e. human happiness and low carbon development), while trying to operationalise and accommodate economic growth opportunities. The complex interplay between the three core goals of Bhutan actually exposes the significance of this research in light of similar goals for achieving global sustainable development.

It is hoped that this research will provide important insight to policymakers in Bhutan on how to move forwards, while also adding new knowledge to the wider research community that is applicable to many developing countries and their policy makers attempting to pursue a low carbon growth pathway.

1.6 Structure of the thesis

The thesis is comprised of six chapters. A summary of each chapter is provided below.

<u>Chapter 1</u>

This chapter has outlined the background of the research field, the scope and aim of the research and the significance of the research.

<u>Chapter 2 – Literature Review</u>

A comprehensive and critical literature review is provided in this chapter. It highlights the extant literature on climate change and low carbon development, theoretical underpinnings for emissions reduction, carbon neutral pledges, energy policy modelling for emissions reduction, and climate policy and human wellbeing.

<u>Chapter 3 – Research design and Methods</u>

This chapter provides an extensive coverage of how the research has been designed and the various methods employed to deliver the research aim. It outlines both quantitative methods, such as the energy–economic modelling task and regression analysis, and qualitative methods, such as interview analysis and drawing inferences from existing literature.

Chapter 4 – Overview of publications

This chapter provides an overview of the five publications. The full paper, as published in the respective journals, is presented in the Appendix.

Chapter 5 – Results and Discussion

This chapter integrates the results and discussions of the five publications, as well as additional results from modelling undertaken as part this exegesis, which led to the key insights and findings of the thesis. Rather than highlighting the individual findings from each of the publications, this chapter interlinks the key results to the relevant research sub-questions put forward under the research aim and objective outlined under Section 1.5 in Chapter 1.

Chapter 6 – Conclusion and Recommendations

This concluding chapter provides the key message within the four sub-questions that were posed at the beginning of the thesis. It then outlines opportunities for future works.

The enclosed Appendices to this exegesis comprise the full-length articles of the five publications. Also, a sample of an interview response provided by one of the participants is appended for a ready reference to provide some perspective on how the interviews were conducted (for details, see Publication 2).

Chapter 2 Literature Review

A comprehensive and critical review of the existing literature was undertaken; both grey literature and peer-reviewed scholarly works were examined. These are discussed in this chapter, beginning with low carbon and climate policy, followed by national level carbon neutrality, then environmental impact theories, including the IPAT model and its variants, which is used as a theoretical basis, as well as the Environmental Kuznets Curve (EKC) theory. The last two sections of the Literature Review deliberate on energy policy and the conceptual framework, demonstrating the cross-disciplinary approaches undertaken in this thesis.

2.1 Climate policy and low carbon development

Climate change is a pressing need and a significant priority for human society to both mitigate and adapt to (IPCC, 2014; UNFCCC, 2016; United Nations, 1992). Rauland and Newman (2015a) mention climate change, along with resource depletion and rapid urbanisation as the three wicked problems that the world is currently facing. Rittel and Webber (1973) framed the term ‘wicked problems’ to characterise the inherent uncertainties and difficulties around social planning and policies. Lazarus (2009) and Levin et al. (2012) go even further, calling climate change a super-wicked problem and a ‘social mess’. The wicked nature of climate change is clearly demonstrated through the decades of contested global climate negotiation, despite the critical role played by the IPCC at the science–policy boundary (see Beck and Mahony (2018) for a review of the role of IPCC).

Dai, Xie, Zhang, Yu, and Wang (2018) argue that the withdrawal of the United States of America (USA) from the Paris Agreement potentially increases the costs of climate mitigation for other nations, such as India and China. This suggests that political cynicism can exacerbate the wicked nature of climate change. The viewpoints that GHG mitigation will harm economic growth is at the root of this contestation (Van Den Bergh, 2017), which is further complicated by equity considerations (Klinsky et al., 2017; Robiou du Pont et al., 2016). Knutti and Rogelj (2015) provide a comprehensive narrative on issues relating to science, politics and equity on climate change and CO_2 emissions. The debate as to whose responsibility it is to take action also persists, especially how to assess equal sharing efforts (Costa, Rybski, & Kropp, 2011; Liu, Fujimori, & Masui, 2016; Yedla & Garg, 2014). A global stocktake of the national climate legislation and strategies between 2007 and 2017 reveal that the number of countries with either climate strategy or climate legislation increased over that period from 21% to 48%, but for climate legislation specifically it only increased moderately, from 16% to 24% (Iacobuta, Dubash, Upadhyaya, Deribe, & Höhne, 2018). This suggests that climate policy is highly variable among member nations, with some taking more actions than others, and relatively few actually implementing legislation. Dolsak (2001) showed that emission reduction commitments depend on the incentives offered and the abilities of a country to impact the emission levels globally. These also affect a country's capacity to adapt to climate change impacts. Mitigation and adaptation, two broad categories of climate policy (IPCC, 2014), are discussed in the next section.

2.1.1 Climate change mitigation and adaptation

Considering the need to curb emissions, as well as to cope with the impact of changing climate, the focus of global climate change negotiations has been centred around both mitigation and adaptation (Dolšak & Prakash, 2018; Halsnæs & Verhagen, 2007; IPCC, 2014). Mitigation and adaptation complement each other and it has been an on-going challenge to show how they can support sustainable development (IPCC, 2014, 2018). Considering that climate change is a global commons problem, mitigation costs are local while providing global benefit. This is significantly different from the case of adaptation, where both benefits and costs are local (Greenhill, Dolšak, & Prakash, 2018). However, there are others who argue that a focus on adaptation actions can crowd out mitigation activities. Greenhill et al. (2018) argue that educating people around the cost of adaptation could increase their willingness to mitigate climate change. Climate change adaptation is about building resilience to cope with the immediate impacts of a changing climate on socio-economic activities, many of which are considered to be disaster management issues (Dolšak & Prakash, 2018). Such activities are carried out through National Adaptation Programmes of Action (NAPA).

On the other hand, climate change mitigation looks at long-term emissions reduction to stabilise the GHG concentration in the atmosphere. Countries identified as Annex 1 parties (developed economies) to the Kyoto Protocol, were to take the lead on this action (United Nations, 1992). Now, the Paris Agreement requires both developing and developed countries to identify and commit to their Nationally Determined

Contributions (NDCs) (UNFCCC, 2016). Mitigation strategies are formulated through Nationally Appropriate Mitigation Actions (NAMAs). Interestingly, Fukuda and Tamura (2010) treat carbon neutrality as a category of NAMA. As carbon neutrality is a core element of this thesis, this will be discussed further in Sections 2.6 and 2.7.

Developing countries are said to be not only more vulnerable, but also do not have the human resources or financial capacity to cope with the impacts of climate change – an adaptation deficit (Fankhauser & McDermott, 2014), which has to a large extent been caused by developed countries in the process of their economic development since the Industrial Revolution (UNDP, 2011b; United Nations, 1992). For Asian countries, the co-benefits of climate change mitigation in terms of human health and minimising their adaptation requirements is 6% of GDP, which exceeds the cost of mitigation at 2% of GDP (Xie et al., 2018). Despite these co-benefits, the difference in the scope of mitigation and adaptation leads to varying degrees of financial requirements, which is a critical element in the North–South debate (Bowen, Campiglio, & Herreras Martinez, 2015), and is discussed in the next section.

2.1.2 The North–South debate

Climate finance underscores the North–South debate on mitigating climate change (Prys & Wojczewski, 2015). The lack of an agreement between developed countries and developing countries was evident from the failure of the 15th COP meeting in Copenhagen to produce a binding agreement. It instead produced the less formal 'Copenhagen Accord', signed only by a few (though powerful) UNFCCC members (UNFCCC, 2009). Such debate largely arises from the right to development (sidelining emissions reduction that could come at additional costs) maintained by developing countries and the challenges to financing carbon abatement with the likely impact on their economic growth, argued by both developing and developed countries. For example, Kainuma, Miwa, Ehara, Akashi, and Asayama (2013) argued that the total investment costs required for a country to move towards low carbon will be higher for non-Annex 1 than for Annex 1 countries commensurate to more emissions reduction possibilities in the former than the latter. Furthermore, since the enforcement of the Kyoto Protocol, emission reductions of one million tonnes on average by each of the Annex 1 parties were found to decrease their economic growth rate by 1 to 2% relative to the non-Annex 1 parties (Cifci & Oliver, 2018). This shows that emission reduction can hinder economic growth, though at a relatively small proportion of GDP. To this end, Northrop (2017) warns that climate stabilisation and sustained economic growth are incompatible, as there is no evidence of absolute decoupling despite evidence of relative decoupling (Newman, 2017; OECD, 2012). Nevertheless, several studies have also found that the costs of inaction (e.g. adaptation) will be substantially higher (Garnaut, 2011; Lemoine & Traeger, 2016; OECD, 2012; Stern, N., 2008), especially the burden on future generations (IPCC, 2014).

Regardless, the issue remains that likely additional costs required to mitigate climate change could hinder economic growth for developing countries, which are still dealing with poverty and trying to raise general living standards (Jakob et al., 2014). This had been emphasised in many of the meetings of the Conference of Parties (COP) (UNFCCC, 2010, 2014, 2016). In light of this, Rao and Baer (2012) proposed a 'decent living emissions' framework to account for energy requirements for basic goods and services to enable a minimum living standard for the developing countries that should be exempted from having a carbon budget imposed on them. Similarly, on the basis of global population and global CO_2 emissions, Yedla and Garg (2014) calculated minimum per capita emissions, which they call 'development space' from a social equity perspective. However, this debate appears to be narrowing, in that the commitment to emissions reduction is converging between the developed and developing countries (Lachapelle & Paterson, 2013). Schreurs (2012) makes an interesting case that despite gridlock in international climate negotiations, the race for green technologies among key nations such as Japan, USA, Germany and China could bring in the needed technological solutions to mitigate climate change.

2.2 Paris Agreement and Sustainable Development Goals

The Paris Agreement is said to have produced the required momentum towards climate stabilisation (Höhne et al., 2017; Iyer et al., 2015). It still calls for developed countries to take the lead for both mitigation and climate finance for developing countries. However, it is criticised for not containing adequate precautionary provisions to address vulnerable countries and communities in terms of adaptation, finance and impacts arising from temperature increases (Sharma, 2017). Nonetheless, the unanimous acceptance of the global SDGs in 2015 (United Nations, 2015) placed climate change action as one of the 17 goals. The transition to low carbon development (LCD) is seen as essential in order to avoid devastating changes to climate (Nishioka, 2016; Reilly, 2013). Research has shown how different forms of human settlement and communities can achieve targets under both the Paris Agreement and the SDGs (Teferi & Newman, 2018; Voytenko, McCormick, Evans, & Schliwa, 2016; Wiktorowicz et al., 2018). The 16th COP, held in Cancun (UNFCCC, 2010) mentioned that a paradigm shift is needed towards a low carbon society in order to stabilise climate change while providing opportunities for sustainable development.

2.3 Towards low carbon development

Mulugetta and Urban (2010) and Urban (2010) state that LCD should align with the principle of sustainable development. This aligns with a Low Carbon Society (LCS) initiated by Japan and the United Kingdom in 2006, which sought to achieve low levels of carbon emissions at nation-state level by reducing consumption and behaviour adjustment (Nishioka, 2016; Skea & Nishioka, 2008). To assess the socio–technical transformation required to achieve their objective, the LCS formulated two broad scenarios: vision A – a technology-driven urban lifestyle, and 'Vision B' – a slow-paced, value-based nature-centric development with a localised production and consumption system (Skea & Nishioka, 2008). Both visions were found to lead to a low carbon society, suggesting compatibility between economic development and climate mitigation. Furthermore, Urban (2009, 2010) suggested LCD as a development pathway that can bring socio-economic growth alongside being climate friendly. Thus, pursuing LCD need not necessarily deter economic opportunities, which can be associated with Ecological Modernisation theory, one of the dominant environmental impact theories that is explained in Section 2.7.

The literature on LCD and the LCS do not explicitly state what level of emissions reduction is required. LCD is popularly accepted as 'using less carbon for growth' (Department for International Development [DFID], 2009).

2.4 From low carbon development to carbon neutrality

The fact that 197 countries have announced their intention to reduce emissions and pursue low carbon development in the Paris Agreement, and only 19 nation-states have pledged for carbon neutrality, demonstrates how much more ambitious and challenging carbon neutrality is than striving for LCD.

The scope and depth of carbon neutrality is understood in several different ways. For example, some see carbon neutrality as an idealised emission reduction target that goes beyond the goal of 80% reduction by 2050 (Birchall, 2014), while for others it is a generous public goods target (Flagg, 2015) that can be provided by an egalitarian society. The United Nations Environmental Programme calls it *Climate Neutrality* for living with no net GHG emissions (UNEP, 2011). There are others who consider carbon neutrality at the micro level, such as products, services, organisations, community and urban development (Rauland & Newman, 2015b). Carbon neutrality does not appear to be properly defined for large entities like nations or cities though it has strong definitions at the level of a firm or an individual; even the Carbon Neutral Cities Alliance, which aims for deep decarbonisation, suggests that each member applies it in the context of their own energy system and socio-economic structure (Tozer & Klenk, 2018). For the Carbon Neutrality Coalition (2017), planning for carbon neutrality seems to imply net zero GHG emissions. Rogelj, Schaeffer, et al. (2015) point out that neutrality is an ambiguous term and insist that the scientific term - net zero carbon emissions - be used instead of carbon neutrality. However, Tozer and Klenk (2018) maintain that the term neutrality provides flexibility and maintains the vision of the future for rapid transformation to avoid climate catastrophe. In this thesis, carbon neutrality is defined as 'socio-economic activities with net zero emissions' (see Publication 1). The next section examines at how Bhutan, a country who has already achieved carbon neutrality, defines it and intends to maintain carbon neutrality at the national level.

2.5 Carbon neutrality at the national level

There is only limited research on carbon neutrality at a nation-state level, mostly undertaken as part of doctoral theses. For example, Flagg (2015) investigated why some nations made carbon neutral pledges in an in-depth study for Costa Rica, and Birchall (2014) investigated the case of abandonment of the carbon neutral pledge by New Zealand, the first nation-state that pledged for carbon neutrality. Flagg's (2015) case study of Costa Rica seems to stand at the starting point of the carbon neutral arena by enquiring about why and what makes nations pledge for carbon neutrality. It then examines the underlying factors that lead to the pledge, such as small population, good governance and lower income inequality gap. Interestingly, studies on emissions and human wellbeing place Costa Rica as one of the privileged few nations that fulfil the criteria for Goldemberg's Corner – which refers to per capita carbon emissions below one tonne and life expectancy above 70 years (Lamb et al., 2014; Steinberger &

Roberts, 2010). The literature on interconnecting human wellbeing and carbon emissions is outlined in Section 2.9.

New Zealand's case study, by contrast, revealed that the change in political leadership was a critical factor behind the termination of the carbon neutral pledge (Birchall, 2014). It is clear that those two studies create an 'empty wedge', in that Flagg (2015) revealed the conditions under which a nation-state pledges for carbon neutrality, while Birchall (2014) highlighted the factors that lead to abandoning the carbon neutral pledge. Thus, the question of how countries sustain the carbon neutral pledge and avoid it from failing, is argued to be more critical, but it remains a gap in the literature. This thesis addresses the question by investigating the future of Bhutan's carbon neutral goal and its interplay with its GNH and economic growth policies.

Flagg (2015) describes carbon neutrality as a generous public good that benefits the entire society. This suggests that poorer countries may struggle with this goal because carbon neutrality entails emissions reduction, which requires huge investment in infrastructure and processes. How a developing country such as Bhutan, approaches carbon neutrality is therefore of significance in a global context. Citing lack of information, Bhutan, along with two other countries, was excluded from the in-depth studies by Flagg (2015). It is often the case that Bhutan gets excluded from in-depth research possibly because it is very small but also it's carbon neutral pledge is not well known in academic literature. However, the case of Bhutan is of particular merit since it is the only nation to have achieved carbon neutrality at present, even as they pursue their unique GNH strategy in parallel. This could be of great interest to the contemporary world of sustainable development goals (SDG) and the Paris Agreement.

2.6 Theoretical foundation for emissions reduction

This section elaborates on the IPAT model and its variants (ImPACT and STIRPAT) as the theoretical underpinnings that relate environmental impact to its various drivers.

The IPAT model was first proposed by Ehrlich and Ehrlich (1972), and is shown in equation (1):

$$I = PAT \qquad (1)$$

where, I = Impact; P = Population; A = Affluence; T = Technology.

This is expanded by most using the equation as: I = PxC/PxI/P or Population x Consumption per capita x Impact per unit of Consumption.

Considering CO_2eq emissions as the principal environmental impact from human activities in the carbon constrained world, which is also at the core of this thesis, a variant of the IPAT model, called ImPACT (also popularly known as Kaya Identity) is used by many (Fankhauser & Jotzo, 2018; IPCC, 2000; Kaya, 1990; US EIA, 2016) to understand emissions from energy consumption as shown in equation (2). The 'C' in the ImPACT essentially captures energy consumption.

$$CO_2 = pop \times (GDP/pop) \times (Energy/GDP) \times (CO_2/Energy) \quad (2)$$

where, population = (pop), economic growth = (GDP/pop) and its associated energy intensity (Energy/GDP), and the carbon intensity of the energy used in the economy = (CO_2/Energy). The last two terms represent 'T' in the original IPAT. With regard to the four drivers, it is cautioned that these terms cannot be treated either as the fundamental drivers of emissions nor as independent terms (IPCC, 2000). This suggests the possibilities of other underlying drivers that this equation may fail to capture.

In this vein, research was conducted that appropriately modified the IPAT and Kaya Identity as per data availability and the context of analysis. For example, Dietz and Rosa (1997) reformulated the IPAT to its stochastic form called STIRPAT to conduct regression analysis, where 'T' is said to account for all other variables not captured by P and A, such as the structural elements, institutional set-up and the governance system. STIRPAT underpins the methodology in Publication 3. From a sustainability viewpoint, Waggoner and Ausubel (2002) aptly relate the PACT terms to core actors in human society – population to parents, income to workers, energy intensity to consumers and carbon intensity to producers. They call C and T the sustainability lever to counter the sustainability challenge from P and A.

Similarly, Diesendorf (2014) used the IPAT model to argue for a move towards achieving a sustainable energy system, which he calls the Great Transition to mitigate climate change. Elsewhere, IPAT has been modified to IHAT to change the unit of analysis to number of Households (H) rather than Population (P) (MacKellar, Lutz, Prinz, & Goujon, 1995). In a similar fashion, Mavromatidis, Orehounig, Richner, and Carmeliet (2016) modified the T terms to measure energy intensity per unit of floor area in buildings. Fischer-Kowalski, Krausmann, and Pallua (2014) use IPAT to weave the story of human-environment relationship since AD 1 and they support the concern of the original IPAT.

It is self-explanatory from equations (1) and (2) that carbon emissions can be reduced if all the factors decrease or whenever there is a net decreasing effect. However, the IPAT identity was also criticised for painting a far too gloomy future for human society (Goklany, 2009; Newman, 2011). These can be analysed side-by-side while explaining the terms in equation (2).

2.6.1 Examining ImPACT

The first term 'pop', represents the total population served by that economy. Policy intervention on population is considered to be highly sensitive and fraught with ethical issues (Newman, 2011; Nie, 2014). IPAT essentially underscores population as the main driver of environmental impact due to the population 'scale effect' (Ehrlich & Holdren, 1971). Empirical research shows that this scale effect depends on the interplay between demographic structure, energy consumption and the level of economic development (Zhang, Z., Hao, Lu, & Deng, 2018). There are others who assert human ingenuity is the ultimate resource (Simon, 1981) that can deliver innovation and advancement through design and new technologies to make a sustainable world (Goklany, 2009; Newman, 2011; Rauland & Newman, 2015a; Wang, C., Engels, & Wang, 2018). Similarly, Wang, H. (2016) argues that the impact of population can be reduced through access to education and changing people's behaviour towards low carbon products and services. In places where the world is becoming increasingly urbanised, urban density is seen as a sustainability multiplier, especially in the knowledge-based economy (Newman et al., 2017; Newman et al., 2019). Thus, in some situations, increasing population may improve environmental impact due to economies of scale and scope for upgrading infrastructure or introducing new types of infrastructure such as trains (Newman, 2015). Following this, others have demonstrated evidence of a reduction in per capita carbon emissions with urbanisation (Lin & Zhu, 2017; Zhang, N., Yu, & Chen, 2017) especially where cities that could take advantage of advance technologies to enable sustainable urban transport (Glazebrook & Newman, 2018). This is further discussed in terms of the Environmental Kuznets Curve in section 2.7.

Toth and Szigeti (2016) warn that over-consumption, rather than population, is a threat to environmental quality. More importantly, they reflected that "as nations or individuals, we should not strive in a competitive way to accumulate more and more wealth at the cost of others, but we should work cooperatively on our happiness-efficiency" (p. 290). This suggests the need to enhance happiness through concerted collaboration. However, happiness or wellbeing itself is a contested concept, which is explored further in Section 2.9 and in Publication 5 where GNH is also seen to have growth outcomes due to the need for fairness and sufficiency in an economy.

The second term, 'GDP/pop' or affluence, is one of the main drivers that affects Impact. GDP per capita is widely used as a measure of national economic growth. As income increases there is an inherent tendency (called 'propensity' by economists) to consume more and more. Given that this factor represents economic opportunities, no government wants to decrease this factor, despite its potential to mitigate carbon emissions (Stern et al., 2016; US EIA, 2016). This suggests that policy intervention to reduce either P or A is contentious and highly debated.

The third term, 'Energy/GDP' measures the energy input needed to produce a unit of economic output, which can essentially be addressed by energy-efficiency policy and/or through structural changes in the economy – notably by decreasing the share of energy-intensive industrial production while increasing the share of the service sector, which is less energy intensive (Fankhauser & Jotzo, 2018).

The fourth term, 'CO_2/Energy' measures the carbon content of an energy system that can also be termed decarbonisation (Fankhauser & Jotzo, 2018; Goldemberg & Prado, 2010). It can be addressed by shifting to low carbon energy sources.

A decomposition analysis using Kaya Identity for Australia's GHG emissions from 1990 to 2013 (Shahiduzzaman & Layton, 2015) showed that the effect of affluence and population on GHG emissions was positive (in a statistical sense), while technological advancement and structural changes may have had a negative effect (in a statistical sense) on GHG emissions. This suggests that managing GHG emissions is a careful interplay among these four factors, which informs climate policymaking and implementation by nation-states.

Technological advancements have leveraged resource efficiency and sustainable consumption (Hargroves, Desha, & von Weisaecker, 2016; Hargroves & Smith, 2006;

IRP, 2017). Hatfield-Dodds et al. (2017) argued that resource efficiency can reduce global resource extraction and emissions by 28% and 15% respectively by 2050 compared to the trend in 2015. However, Ehrlich and Holdren (1971) argued that technological fixes only shift the problem rather than removing it. Similarly, Toth and Szigeti (2016) warn that humans cannot ignore or apply brakes on the thermodynamic laws and there is much evidence to support the Jevons paradox (Jevons, 1965) also known as the rebound effect – that users of efficient technologies tend to consume more. However, others argue for technological efficiency, re-composition of goods and reduction of consumption (a sufficiency approach) to reduce emissions (Gough, 2017). This suggests the complementarity of the Efficiency and Sufficiency strategies to reduce impact. These contested issues, even at the levels of individual drivers of CO_2eq emissions (i.e. the environmental impact), clearly indicate the complex geopolitics of global climate negotiation (UNFCCC, 2016; United Nations, 1998). The complexity substantially increases with the need to incorporate the 17 SDGs into national development plans.

2.6.2 Implications for Bhutan

The implications of equations (1) and (2) (see 2.6) to Bhutan for its carbon neutrality is that the total CO_2eq emissions should be less than or equal to its forest carbon sequestration capacity, which is estimated at 6.3 million tonnes of CO_2eq (NEC, 2011). This is the carbon budget within which Bhutan can manoeuvre, to test and explore its socio-economic development pathways. Given that Bhutan already has a forest cover of 71% (MoAF, 2017), which has been maintained over the past several decades, the key challenge for Bhutan is to reduce the emissions from its growing economy (GNHC, 2011) through strategic policies relevant to the four factors shown in equation (2). This research argues and demonstrates that these four factors can be captured by an energy–economic model through demand projection, which can be linked to population, household and economic growth, and by incorporating various technological choices. Energy models and long-term energy–economic planning for climate policy are reviewed within Section 2.10.

While IPAT and its variants provide a theoretical framework with which to assess and explain the human dimensions of environmental impact, other empirical studies have used the Environmental Kuznets Curve (EKC) hypothesis (Chow & Li, 2014;

Grossman & Krueger, 1995; Munasinghe, 1999; Panayotou, 1993; Stern, D. I., 2004; Stern, D. I., Gerlagh, & Burke, 2017; Yang, G., Sun, Wang, & Li, 2015) to substantiate the relationship between economic growth and environmental quality.

2.7 Environmental impact theories and Environmental Kuznets Curve

The Jevons paradox (Jevons, 1965) explains the rebound effect of energy efficiency. Toth and Szigeti (2016) warn that thermodynamic laws cannot be ignored, which implies the need for a consumption ceiling so that we do not transgress the planetary boundary (Rockström et al., 2009; Steffen et al., 2015). Furthermore, existing alternative progress indicators, such as the Environmental Sustainability Index, Ecological Footprint and Genuine Savings, question the sustainability of the current socio-economic patterns around the world (Pillarisetti & van den Bergh, 2008).

Unsurprisingly, the need to have a consumption ceiling, which arguably points towards a normative threshold, is visible in the GNH strategy of Bhutan, which is built around sufficiency and the middle path (CBS, 2012, 2016; Rinzin, 2006; Thinley, 2005). 'Sufficiency' in the GNH strategy represents 'how much is enough?', which is based on value judgements (CBS, 2012). Griese, Kumbruck, and Schlichting (2015) mention that sufficiency originated from the Latin verb 'sufficere', which means 'to be sufficient' with the bare necessities. Hayden (2015) succinctly places the case of Bhutan's GNH-based development model into the much-debated space of environmental impact of economic growth through the sufficiency lens. These advocates of sufficiency reject the 'decoupling' concept that is promoted by green growth and green economy, arguing that technological efficiency gains are offset by the scale effect from rising income and population (Hayden, 2015) and that it cannot alleviate ecological crises (Barbier, 2011). However, the proponents of decoupling see a Green economy as a win-win solution to pursue economic growth while protecting the environment (ADB, 2012; Jänicke, 2012; Loiseau et al., 2016). This has roots in the Porter hypothesis (Porter & van der Linde, 1995), which posits that environmental regulation can lead to innovation and resource productivity and make a business enterprise more environmentally efficient, as well as profitable. In fact, the Carbon Neutral Cities Alliance sees a Green economy as an imperative to achieve carbon neutrality (Tozer & Klenk, 2018).

The concept of decoupling as a policy lever was upheld by the International Resource Panel (IRP) of the United Nations Environmental Programme (IRP, 2017; UNEP, 2014) and by independent research team (Smith, M. H., Hargroves, & Desha, 2010). The IRP (2017) recommended absolute decoupling along with reduced consumption levels in the developed nations and relative decoupling in the developing nations to minimise the environmental impact of human activities. Newman and Kenworthy (2015) described decoupling "as a major global agenda for enabling sustainable development" (p. 77) and they presented evidence for decoupling economic growth from fossil fuel consumption around the world. Similarly, using scenario modelling, Schandl et al. (2016) showed that decarbonisation and dematerialisation can be achieved without affecting socio-economic wellbeing, even at the global level. In this vein, even absolute decoupling was shown to be plausible if the rebound effect is addressed along with radical resource efficiency (Meyer, Hirschnitz-Garbers, & Distelkamp, 2018).

These arguments were reflective of the burgeoning debate between the two dominant environmental impact theories: the Ecological/Economic Modernisation theory (EMT) and the Treadmill of Production theory (TPT). EMT argues for technological innovation and diffusion, and structural changes to reduce the environmental impact of economic growth (Bergendahl, Sarkis, & Timko, 2018; Huber, 2004, 2008; Mol & Spaargaren, 2000; Spaargaren & Mol, 1992). The TPT argues that economic growth in itself causes environmental degradation. The debate basically seeks to answer the question of how to leverage economic opportunities while reducing environmental impact. This points towards the dilemma of development, which is at the heart of the sustainability discourse. Tozer and Klenk (2018) pointed out that carbon neutrality (as seen by the Carbon Neutral Cities Alliance) has a strong modernisation element. Xue, Walnum, Aall, and Næss (2017) constructed two different development pathways based on the ideals of EMT and degrowth to assess the likely success of the 1.5°C agenda. They concluded that the agenda can succeed under a degrowth pathway, but is likely to face severe resistance from the prevailing socio-cultural patterns, while the EMT pathway will require an unrealistic reduction of eco-intensity by 65%. On the contrary, Hargroves et al. (2016) showed that radical resource productivity in the order of factor 5 was found to be possible with some firms already using it. The need to enable productivity in developing countries was emphasised by the World Bank in its report on Innovation Paradox (Cirera & Maloney, 2017). However, Kallis (2017) argues that dematerialisation can only happen under degrowth.

Both EMT and TPT theories substantiate their argument by gleaning from the EKC hypothesis, which posits an inverted U-shaped curve between economic growth and environmental quality (Grossman & Krueger, 1995; Panayotou, 1993). The EKC theory is used to analyse a range of different environmental dimensions, it uses many different sets of time series data and most countries/country have been investigated (Yang, G. et al., 2015). Urban and Nordensvärd (2018) deployed the EKC concept to explain low carbon energy transitions and evidence of decoupling in the Nordic countries: Denmark, Norway, Sweden, Finland and Iceland. Existing literature on the environmental impact of economic growth presents mixed results, as well as partially supporting both EMT and TPT perspectives (Adua, York, & Schuelke-Leech, 2016; Jorgenson & Clark, 2012) and this literature mostly uses regression analysis to assert their claims. Jänicke (2008) praised EMT for modernisation of the market economies while improving the environment, but warned about the inherent limits of the EMT, which are evident from climate change, biodiversity loss and for failing to remedy the rebound effect that leads to more resource consumption with efficiency improvement. Interestingly Hovardas (2016) presented EMT as an attempt to link the rebound effect and Porter hypothesis. It is often suggested that the EMT has its roots in neoclassical economics and that of TPT in ecological economics; Konchak and Pascual (2006) compared and contrasted neoclassical economics and ecological economics and argued that both paradigms have their own limitations, concluding that both require a forward-looking philosophy to remove barriers and create solutions for the new era rather than entrenched ideals being held onto into a bitter future.

Considering that sustainability is at the core of this debate, Hedlund-de Witt (2014) argued for a reflexive world view to accommodate the best parts of the disparate philosophies. It is also pointed out that the forward-looking approach of humans will play a key role in weaving through the complexities of the sustainability issue – economic, social and ecological (Holling, 2001). This is consistent with the argument of DeFries et al. (2012), to look for 'planetary opportunities' rather than focusing on biophysical limits, that is to utilize human ingenuity to come up with tractable solutions to increase societal needs without breaching planetary boundaries (Rockström et al., 2009). This suggests that it is possible for the two theories to complement each other and find a common ground, which at present may be blinded by estranged ontologies. Thus, it is clear that striking the middle ground could be plausible and is definitely desirable if humanity is to remain within the doughnut of sustainability (Raworth, 2013). This will have implications for long-term global sustainability.

Such research is of interest to Bhutan, since the Green economy is relevant to the pursuit of the carbon neutral goal, along with its middle-income aspirations and the pursuit of a sufficiency-based GNH paradigm to reduce overconsumption that is detrimental to ecological limits. However, it can also lead to further growth if fairness leads to greater consumption for large numbers of people living on low incomes. This is of global significance in academic terms as well as for policy development, in that the interplay between carbon neutrality, which is an imperative to achieve the Paris Agreement, and the GNH paradigm, can together contribute to the sustainable development discourse.

Drawing from the literature, this thesis recognises that the sustainability debate is in essence one between these two theories on the environmental impact of economic growth. This thesis contends that integrating the two theories holds the key to mitigating climate change (if not also the key to sustainability), and aiming for carbon neutrality is the most ambitious and necessary climate policy. Notwithstanding this, both the environment and economic opportunities are indispensable for human wellbeing. This is evidenced by ‘conservation of environment’ and ‘economic development’ forming two of the four pillars of the GNH strategy being pursued by Bhutan (CBS, 2012; Thinley, 2005; Ura, 2015). Economic growth is required to provide liveability in human development, while environment is the larger entity on which humankind depends. In this vein, there is now an emerging research strand that seeks to understand economic growth and the environmental intensity of human wellbeing to define sustainability by deploying the EKC hypothesis (Dietz, Rosa, & York, 2009, 2012; Jorgenson, 2014; Knight & Rosa, 2011; Sweidan, 2018).

2.8 Strategies, challenges and benefits of carbon neutral development

Low carbon transitions are widely acknowledged as complex (Fankhauser, 2013; Geels, Sovacool, Schwanen, & Sorrell, 2017). In particular, Geels et al. (2017) suggest four lessons for low carbon transitions: 1. Transition is multidimensional and requires policy mixes and engagement of various actors in the system; 2. Transition requires analysis of the political system besides policy analysis; 3. Transition should increase the solution space beyond techno-economic; and 4. Transition should manage phase-outs while supporting innovation.

Transition to a low carbon economy is highlighted as a great transformation that can be compared to the Industrial Revolution (Messner, 2015), which requires transformation in the energy system with implications on the day-to-day functioning of the socio-economic system (Rosenbloom, 2017). Rosenbloom (2017) further reflects on three different perspectives labelled 'pathways', namely biophysical, techno-economic and socio-technical pathways, to elucidate the theory and governance of low carbon transitions. The pathways are differentiated on the basis of temporality and the actors involved, and it is stated that they may overlap, with each emphasising different yet interconnected dimensions. This resembles the three different approaches outlined by Geels, Berkhout, and van Vuuren (2016): integrated assessment models, socio-technical assessment and action-based research. They argue that each approach plays out on a different spatial level (international level, nation-state level and local level) and that they cannot be substituted or replaced by the other ones due to differences in their underlying philosophy and ontological assumptions.

Similarly, the World Bank group outlined three principles to pursue LCD: 1. A policy package beyond carbon tax, 2. Protecting the vulnerable; and 3. Planning in advance (Fay et al., 2015). Mulugetta and Urban (2010) and Urban (2010) categorised the field of LCD into four different quadrants based on the production–consumption continuum as: 1. Low carbon growth, 2. Low carbon lifestyle, 3. Equilibrium economy; and 4. Coexistence with nature. Their categorisation placed Bhutan under the fourth category, attributing its GNH principle as the reason, although without further explanation. They stated that the four groups could overlap with one another to form mixed policy choices in any country, depending on its socio-economic capacity, and suggesting the possible practical use of their proposed categorisation. This seems notable and this thesis will show how the institutional framework built around its GNH strategy places Bhutan in a unique and desirable pre-condition situation to pursue carbon neutrality and human wellbeing.

LCD is also argued to be the only alternative that could halt climate change while also having clear social benefits (ADB, 2016; Mulugetta & Urban, 2010). These arguments were also supported by research on climate stabilisation that emphasised the need to go for a net zero carbon goal for there to be a 1.5°C consistent world (IPCC, 2018; Rogelj, Luderer, et al., 2015; Rogelj et al., 2018). Given such an imperative for deep emissions reduction, wartime experiences that demanded rapid deployment of resources at hand were even suggested as a policy model for the rapid mobilisation of resources to fight climate change, a global common enemy (Delina & Diesendorf, 2013). The reasons cited included uncertainties, disagreements and distributed power (Geels et al., 2017).

Challenges were also highlighted, even for developed countries that are also endowed with renewable energy and have more financial capacity. For example, Ydersbond (2014) highlights that Sweden and Norway are struggling to transform their energy system to low carbon despite both having renewable energy share above 50%. Similarly, the need for greater policy and financial support to increase low carbon transformation in the transport and industry sector of Nordic countries were raised by Urban and Nordensvärd (2018). This is likely to also be a challenge for Bhutan with the share of oil and coal together in the final energy consumption increasing from 27% in 2005 (DoE, 2007) to 37% in 2014 (DRE, 2015) despite abundant hydropower potential. Moreover, Bhutan is a developing nation, unlike the Nordic countries, which are wealthy enough to afford the transition. Mulugetta and Urban (2010) emphasise that LCD is not without cost and poor countries usually rely on support from international climate finance.

Bhutan acknowledges that going carbon neutral could mean foregoing some economic opportunities that could be harmful to the environment, while at the same time recognising the possibilities of decoupling economic growth from environmental degradation (GNHC, 2011). In light of this, as pointed out in section 1.4.4, the need to balance economic growth and sufficient energy, while conserving the environment was emphasised in Bhutan's low carbon strategy (NEC, 2012). To address this concern, an energy-economy modelling approach was undertaken in this thesis to see how this could be achieved. This issue further underscores the debate on the environmental impact of economic growth, which was discussed in Section 2.7. The research on carbon neutral Bhutan focused on two pathways with their associated analytical approaches – integrated assessment models and socio-technical assessment through long-term energy-economy modelling. The biophysical pathway and the action-based research highlighted by Rosenbloom (2017) and Geels (2016) remain out of the scope of the present research, which focuses on carbon neutrality at a nation-state level.

Despite the challenges of LCD, there are also many benefits highlighted in the literature. For example, Urban (2010) argues that LCD can also be an opportunity for poor countries to pursue low carbon policy and development, with additional benefits to the country, such as being able to leapfrog old technologies (Schroeder, P. M. & Chapman, 2014). Other case studies supporting Urban's (2010) argument include the Low Carbon Society project (Skea & Nishioka, 2008), which demonstrated economic, social and environmental co-benefits. The case of Kolkata city in India showed that low carbon urban development can be pro-poor, i.e. beneficial to the poor (Colenbrander et al., 2016) and the case of Kigali city in Rwanda show that low carbon development is economically feasible for a low income nation (Colenbrander, Sudmant, Chilundika, & Gouldson, 2018). Similarly, Shakya (2016) quantified the benefits of low carbon development in Kathmandu, the capital city of Nepal, demonstrating its relevance even to poor and land-locked developing countries. At the micro level, carbon neutral or low carbon initiatives can also benefit end-users through reduced utility bills (Rauland & Newman, 2015a; UNEP, 2011).

2.9 Climate policy, human wellbeing and Gross National Happiness

> "A research agenda for fostering universal well-being within environmental limits cannot therefore remain naïve to vested interests embodied in fossil capital." (Lamb & Steinberger, 2017, p.11).

Lamb (2016) raised the need for a theoretical framework to link wellbeing and biophysical resources. Similarly, Lamb and Steinberger (2017) argued about the complexity of linking biophysical resources and human wellbeing, suggesting that the literature on the 'provisioning system' (such as clean air and the environment provided by the natural ecosystem) can provide a theoretical framework to link them. Perhaps the works being undertaken on the four capital approaches that comprise human, social, built and natural capital to human wellbeing (Costanza et al., 2007; Vemuri &

Costanza, 2006) are reflective of understanding these linkages. That is, social and natural capital provide the intangible factors to address human wellbeing. However, wellbeing is a contested research area with divergent approaches, measurement and implications (Bakar, Osman, Bachok, Ibrahim, & Mohamed, 2015; Brand-Correa & Steinberger, 2017; Dodge, Daly, Huyton, & Sanders, 2012; Ryan & Deci, 2001; Tandoc & Takahashi, 2013). Notwithstanding this, two distinct philosophical views on wellbeing – hedonic and eudaimonia – are being recognised as leading to several wellbeing theories (Lamb & Steinberger, 2017; Ryan & Deci, 2001). Hedonic wellbeing is primarily associated with self-gratification by fulfilling a desire and was first defined by Aristippus, a Greek philosopher; while eudaimonic wellbeing is more about an evaluative approach to the quality of life, and is associated with Aristotle (Ryan & Deci, 2001).

Based on the hedonic and eudaimonic approaches, there are three major theories explaining human happiness: the comparison theory, folklore theory and the liveability theory (Hagerty, 1999; Veenhoven & Ehrhardt, 1995). The comparison theory is advocated by Easterlin (1974, 2001) and posits that happiness arises from comparing one's own earlier circumstances or comparing your circumstances with your peer. The notion of relativity is strong in such strands and there is nothing absolute about it – the frames of reference keep shifting. This leads to the Easterlin paradox, which suggests that people can never be happy given their changing frame of mind (Easterlin, 1974, 2001). This theory could perhaps explain the consumeristic rat race that persists as if resources are infinite. This could also help to explain some of the reasons behind global resource depletion – one of the key challenges human society is facing at present (IRP, 2017). The folklore theory explains the notion of happiness as arising from one's outlook on life and cultural influence (and national character), rather than from the prevailing conditions of life (Veenhoven & Ehrhardt, 1995).

Based on analysis of 28 cross-national survey data, Veenhoven and Ehrhardt (1995) concluded that liveability theory is more realistic than the other two theories. The liveability theory explains that subjective happiness is strongly related to the objective quality of living conditions – thus informing universal basic human needs (Veenhoven, 2014; Veenhoven & Ehrhardt, 1995). The theory of universal human need is argued to provide a framework for sustainable wellbeing – wellbeing with a sustainable emissions level (Gough, 2015, 2017). Gough (2017) further argues that the 'Need

Theory' comes with an in-built distributive principle called sufficiency. Thus, from a climate mitigation perspective, eudaimonic wellbeing, for its collective aspect, appears to be favoured over the individualistic features of hedonic wellbeing (Gough, 2015, 2017; Lamb & Steinberger, 2017).

Such collective aspects are present in the formulation of the GNH index. The central tenet of GNH is balancing the material and non-material components of human wellbeing, with its roots in Buddhism (CBS, 2012; Thinley, 2005). However, being cognisant that the core of Buddhism is about taming one's mind, liberation from worldly affairs and denouncing material possessions (Metz, 2014; Tashi, 2004), this research does not delve further into Buddhist theology, as it remains outside the scope of this thesis. Rather this thesis focuses on happiness as seen through the lens of the GNH strategy; that is, having policy implications for worldly affairs, especially in the era of the SDGs and the Paris Agreement on climate policy. Nonetheless, happiness in GNH is not about transitorily feeling good (Thinley, 2005), but it is related to 'wellbeing' (Pennock & Ura, 2011), 'good life' (Metz, 2014), and 'quality of life' (Costanza et al., 2007), suggesting its applicability on a global level. GNH is posited as a holistic development framework that constitutes nine domains and 33 indicators to encapsulate the multidimensionality of human wellbeing (Alkire, 2015; CBS, 2016; Ura, 2015). These are the dimensions of GNH used to model outcomes based on different policy scenarios in this thesis.

The pursuit of GNH is described as a 'big change from a small place' (Metz, 2014). GNH is epistemically and ontologically a paradigm shift away from the prevailing economic growth-only paradigm, which is founded on the notion that material development alone is the key to human wellbeing. This notion and the associated socio-technical system are being shaken by the burgeoning reality of climate change, resource depletion and social inequality. Through its GNH principle, Bhutan is possibly attempting to put the brakes on the relentless pursuit of economic development that inspired some scholars to propose GNH as a model for degrowth (Verma, 2017). The prevailing socio-cultural system in Bhutan is pro-GNH (Allison, 2012; Schroeder, R. & Schroeder, 2014). In Bhutan, the scope of happiness (Mitarai, 2018) is said to be wider, going beyond individuals and to benefit the next generation, as demonstrates in Figure 4.

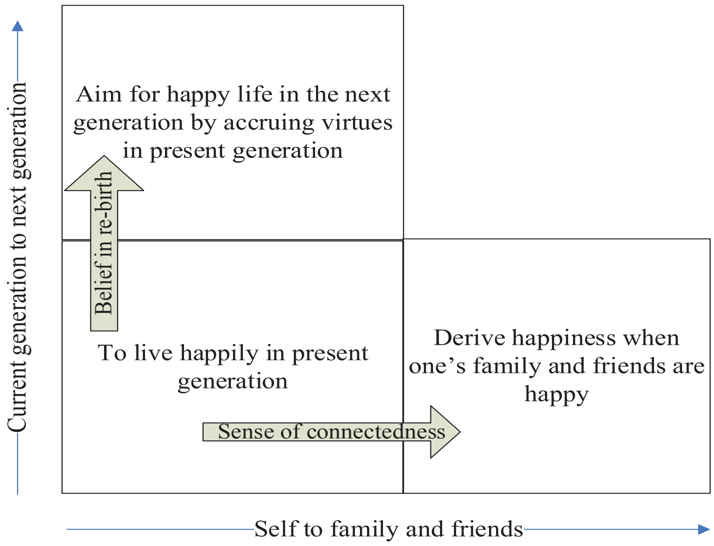

Figure 4. Scope of happiness (adapted from Mitarai (2018))

The GNH survey, which is how the GNH index is measured, discourages participants from comparing their life satisfaction with their neighbours or other people (CBS, 2012). Thus, it is intended to resist the comparison theory. It is argued that happiness in GNH could align with liveability theory and folklore theory, in that it captures both the economic sphere and the socio-cultural sphere of human happiness. Folklore theory connects wellbeing and cultural norms, and this appears to be clearly demonstrated in Figure 3, while the liveability theory connects wellbeing and economic opportunities to provide liveable conditions. No such comparison between GNH and other wellbeing theories in the wider literature were mentioned in any of the GNH documents produced from Bhutan.

The need to balance GNH (wellbeing) and GDP (economic opportunities) is mentioned as a critical area for governance (Ura, 2015) and Lepeley (2017) show that they complement each other. This thesis expands on this area of concern to include GHG and the addition of a carbon neutral pledge to form Bhutan's 3G model, which is at the heart of Publication 1. This takes us to the next section, which considers energy a prerequisite for socio-economic activities, and underpins living conditions, thus, it relates to both economic opportunity and to wellbeing.

2.10 Energy policy for low carbon development

Economic activities and human development require an energy system. The core of decarbonisation is to change the use of fossil fuels for energy to cleaner sources and hence create carbon neutral development. Access to energy services is widely accepted as a key factor for human wellbeing (Brand-Correa & Steinberger, 2017; Castro-Sitiriche & Ndoye, 2013; Goldemberg, 2012; Lamb & Rao, 2015; Lamb & Steinberger, 2017; Nilsson et al., 2012; Ouedraogo, 2013; UNDP, 2002), and the UNDP asserts that "getting energy right is clearly a pre-requisite for sustainable development" (UNDP, 2002, p. 11). Recognising this, energy is now explicitly included as one of the 17 SDGs (SDG 7) (United Nations, 2015).

The dual relationship between sustainable development and climate change was highlighted in Section 2.1. Another example of this is highlighted by Byravan et al. (2017), who showed that enhancing the quality of life in India in terms of meeting basic needs through clean energy access was compatible to achieving their Nationally Determined Contribution (NDC) to the Paris Agreement on Climate Change. Similarly using energy models, Urban (2009) has demonstrated the feasibility of climate change mitigation in China and India without deterring economic growth.

At the global level, keeping to an increase of no more than 2^0C and preferably only 1.5°C rise – the long-term target of the Paris Agreement – the need for large-scale renewable energy sources, carbon removal technologies and reduction in energy use, were strongly emphasised (Rogelj et al., 2018). This suggests the critical role of energy policy for climate policy. Furthermore, based on the laws of thermodynamics energy is argued to be the master resource that forms the ultimate limiting factor for economic activities (Zencey, 2013). In particular, Lamb and Steinberger (2017) posit that wellbeing and emissions are linked through energy consumption and agriculture.

From the Kaya Identity shown in equation (2) in Section 2.6, it can be seen that energy appears in two terms (Energy/GDP and CO_2/Energy), suggesting it as a key contributor of CO_2eq emissions, which can be addressed through appropriate energy policy. Ouedraogo (2013) found a positive long-run causal relationship between energy, electricity and human wellbeing in 16 developing countries. In Bhutan, providing energy access through micro-hydropower at a community level is shown to augment GNH by enhancing health and education, improving the environment and generating income (UNDP, 2011a). Education plays a key role in alleviating absolute poverty (Mehta, 2006) and also increases the likelihood of nations choosing clean and renewable energy (Rahut, Behera, & Ali, 2016). Green and Newman (2017) have shown that transition towards renewable electricity is happening through the increasing uptake of solar rooftop systems in Australia. However, energy consumption is found to have a non-linear and diminishing effect on human wellbeing – that is, higher energy consumption is not necessary to attain higher wellbeing (Mazur & Rosa, 1974; Steinberger & Roberts, 2010). In this vein, a final energy threshold of between 25 to 50 GJ/capita was found to meet a good standard of living (Lamb, 2016).

As mentioned in section 1.5.2, there are only limited studies on Bhutan's low carbon policy, long-term energy–economy modelling, or its carbon neutrality in general. No journal articles have discussed how Bhutan will maintain carbon neutrality while also increasing their happiness into the future.

The techno-economic assessment of an energy system is one of three pathways outlined by Rosenbloom (2017) to explore the challenges of a low carbon transition. Beyond the local level gaps, literature specific to carbon neutrality at national level in general is limited, in particular any that encapsulates carbon neutrality (not just low carbon) and human wellbeing.

Using the Gini Index[3] to characterise social conditions, Bastianoni, Coscieme, and Pulselli (2016) used an Input–Output model (I-O model) to investigate the nexus between economy, society and the environment in five countries. An I-O model is a top-down model used to analyse macroeconomic issues that may arise from policy changes such as taxation, pricing and trade. Bastianoni et al (2016) highlighted the need for a combined understanding of the various disciplinary perspectives to align development towards sustainable patterns. Carvalho, Antunes, Freire, and Henriques (2015) also used I-O model to investigate the trade-offs between the energy–economy–environment and employment in the Brazilian economy. They observed that maximisation of GDP and employment requires increasing energy use and GHG emissions, whereas, minimisation of GHG emission and energy usage reduces GDP and employment. A study on low carbon development in China (Hu, Yuan, & Hu,

[3] Gini Index is a measure of income inequality developed by Corrado Gini (Kaika & Zervas, 2013).

2011) under the economy–energy–electricity–environment framework found that climate change and rising GHG emissions are the biggest sustainability challenge for China and recommend that China reshapes its economic structure and embraces technology innovation to realise its huge potential towards a low carbon economy. This complements the need for technological leapfrogging to realise China's low carbon urban development (Schroeder & Chapman, 2014). These researches again suggest the need for an integrated thesis and framework.

2.11 A conceptual framework

The relevant literature reviewed in the preceding sections deliberated on good quality of life, fair living standards within a sufficiency framework, technological efficiency/decoupling and low carbon discourses. In particular section 2.6 presented the theoretical background and key variables for emission reduction and its associated complexities leading to the confounding debate around environmental impacts of economic development, which was presented in section 2.7. Drawing from these aforementioned sections, a conceptual framework is constructed to capture the complexity of the present research that is deemed to require both qualitative and quantitative research paradigms. A conceptual framework is a representation of concepts (Boylan et al., 2018) or an 'idea context' (Maxwell, 2005) that intends to capture and outline a research, which is informed by the literature and the rough idea that researchers have in their mind. Furthermore, current literature recognises the dual relationship between climate change and sustainable development, which for Bhutan means the nexus between GNH strategy, Carbon Neutral policy and economic growth. This thesis is therefore based on an integrative worldview approach to economic growth, carbon emissions and human wellbeing, which informs the framing of the 3G model for Bhutan highlighted in section 3.3.2 of the exegesis and Publication 1. The key concepts are: efficiency, sufficiency and fairness, and decoupling that are being used in the contemporary sustainability discourse.

These concepts were either implicitly or explicitly invoked in all the five publications as well as in section 5.5 of the exegesis. Sufficiency and fairness are well recognised in the GNH strategy; whereas efficiency and decoupling are key to low carbon economic growth through technological advancement and transition to renewable energy at the end-user levels.

Based on the conceptual framework and the results from the five publications the development of a new, integrated framework is deliberated in section 5.5, which ultimately leads to section 6.5 with a diagram (see figure 9) to answer the main research question.

Chapter 3 Research design and methods

This chapter summarises the methods used and how the required data for the chosen methods were collected. This thesis takes an integrated research approach structured around the integral worldview, considering that Sustainability seeks to embrace various worldviews (Hedlund-de Witt, 2014; Luederitz, Abson, Audet, & Lang, 2017; van Egmond & de Vries, 2011). Worldview is a belief system, a perception about how one sees the world (Irzik & Nola, 2009; van Egmond & de Vries, 2011; Walker, 2017; Wong, 2014). Details on the methods and analytical framework are also outlined in each of the five publications annexed to this exegesis.

3.1 Rationale for research design

Climate change poses significant threats to sustainable development (IPCC, 2014), while sustainability is considered to be a prerequisite for wellbeing (RGoB, 2012a). Recognising this nexus, Bhutan reiterated its carbon neutral commitment in its submission for the Paris Agreement (RGoB, 2015), which eventually became Bhutan's Nationally Determined Contribution (NDC). Alongside its carbon neutral goal, Bhutan also has two other important goals – economic growth for its middle-income aspirations, and the pursuit of societal happiness through its GNH strategy. These three distinct goals form a unique sustainability challenge for Bhutan, which requires a nexus thinking, multidisciplinary approach to address. This thesis, including the papers which constitute it, therefore use a variety of research methods including both quantitative and qualitative.

This section begins by providing a summary of the research design (see Figure 5). The quantitative methods used included modelling and regression analysis. The qualitative methods included semi-structured interviews and a literature synthesis. These methods are further elaborated below. Limitations of the methods and data issues are outlined in the final two sections of this chapter.

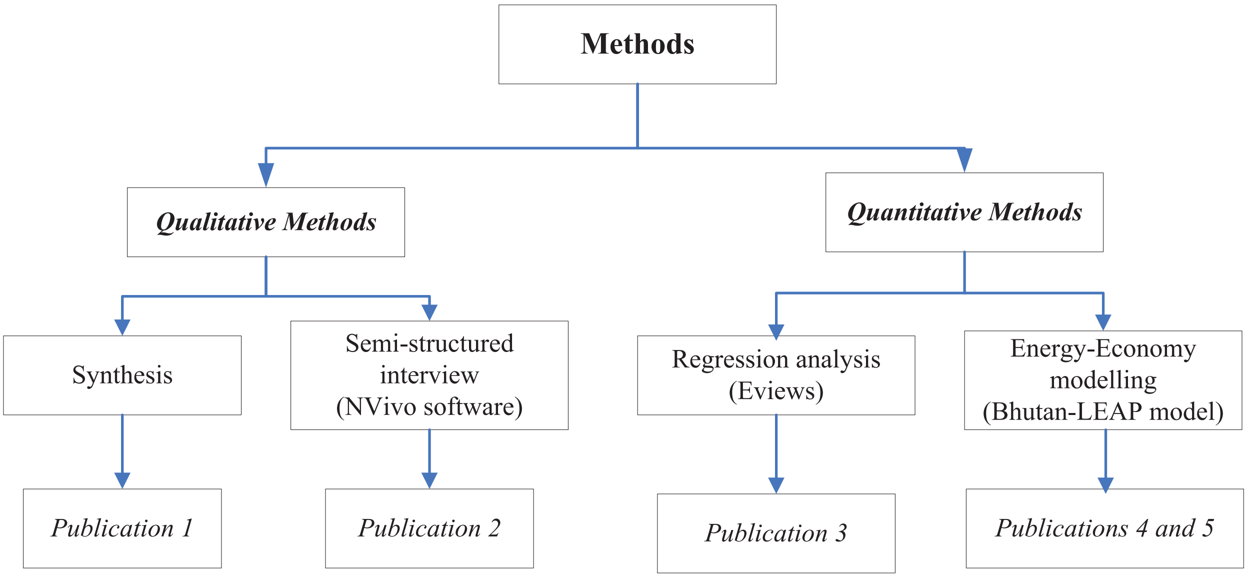

Figure 5. Outline of Methods

3.2 Quantitative research method

Population, economic growth, lifestyle and behaviour, energy use, technology and climate policy are widely recognised as the drivers of carbon emissions (IPCC, 2014). Considering these factors, we refer to the IPAT identity especially its variants STIRPAT and ImPACT (or the Kaya Identity) (see section 2.6), to understand and formulate past development trajectory and the future pathways of carbon neutral Bhutan following the three fundamental steps for achieving carbon neutrality: measuring, reducing and offsetting (Rauland & Newman, 2015b; UNEP, 2011). This research used two quantitative methods, which are outlined in the following two sections.

3.2.1 Energy-economy modelling

An integrated energy-economy model was used to conduct scenario-based long-term energy-economy modelling for emissions reduction. Scenario-based energy modelling is widely applied using a systems approach (Kamel & Dolf, 2009; Krey, 2014; Lund et al., 2017; Nakata, Silva, & Rodionov, 2011; Nerini et al., 2018; Söderholm, Hildingsson, Johansson, Khan, & Wilhelmsson, 2011). A systems approach treat all elements inside a system under investigation as a whole, not in parts (Bertalanffy, 1968). Scenario-based planning allows us to explore the future we want, though future itself remains unpredictable (Costanza, 2014; Lein, 2016; Raskin, Gallopin, Gutman, Hammond, & Swart, 2000; Samadi et al., 2017). As pointed out in Section 2.10, Chapter 2, only limited studies exist on the long-term energy economy modelling for Bhutan and hardly any studies are specific to the carbon neutral policy of Bhutan.

Given that low carbon development is not without cost (Foxon, 2010; Mulugetta & Urban, 2010), providing costing information stands out as a critical contribution. Given that no studies have examined the costs of maintaining carbon neutrality, a Bhutan–LEAP model was developed to elucidate plausible pathways, along with their cost implications, to uphold the carbon neutral pledge (see Publications 4 and 5). The LEAP energy model is a simulation-based energy planning tool developed and licensed by the Stockholm Environment Institute (Heaps, 2016). LEAP is categorised as a hybrid model that combines the features of bottom-up and top-down model (Lopion, Markewitz, Robinius, & Stolten, 2018). It allows users to conduct energy system analysis from a simple energy accounting purpose (DoE, 2010) to a long-term energy policy and climate policy analysis (Ouedraogo, 2017; Shakya, 2016; Urban, 2009; Yang, D. et al., 2017).

Simulation models are said to be more suitable for creating dialogue and open discussions (Lund et al., 2017). The validity of the model's results rest with the techno-economic data sets that were collected from various sources, including grey literature and scholarly works published in peer-reviewed journals. The data used and the limitations associated with them are highlighted in Publications 4 and 5, and further elaborated on in Chapter 5. It is worth noting that the aim of the energy modelling tasks is to explore plausible future pathways rather than predicting the future, which is inherently uncertain.

The data sets comprised of population, number of households and gross domestic product, and various techno-economic parameters related to energy conversion technologies on the supply side and demand technologies used on the demand side, within four economic sectors. The four economic sectors were: residential, service, transport and industry sectors. They were further disaggregated into sub-sectors and end-use energy services, for example, heating, cooking and lighting in the residential sectors, and passenger-kilometres and tonne-kilometres in the transport sector, and tonnes of industrial output. The end-use technologies provide energy services to meet human needs in the residential sector and economic productivity in other sectors. The techno-economic parameters of the data include cost, efficiency, lifespan and the type of energy used by the technologies modelled in the Bhutan–LEAP model. The overall framework for modelling and scenarios analysis is shown in Figure 6.

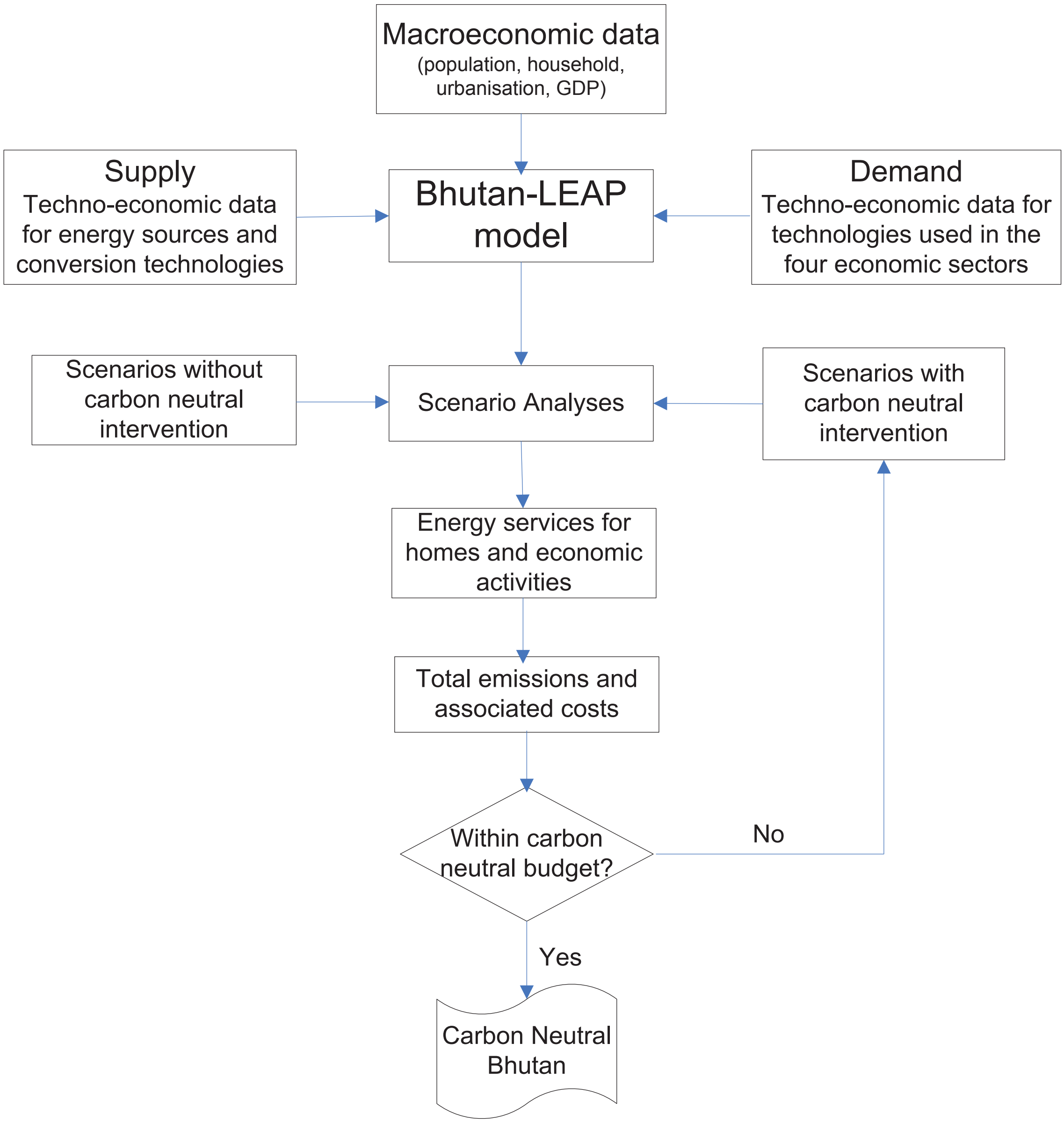

Figure 6. Modelling and scenario analysis framework

The emission factors for the greenhouse gases (GHG) were taken from the Technology and Emission Database (TED) of the LEAP model. While there are six GHG's identified under global carbon accounting standards (United Nations, 1998), the Bhutan-LEAP model only accounted for three dominant GHGs: carbon dioxide (CO_2), methane (CH_4) and nitrogen oxide (N_2O) considering that other GHG's were insignificant for the case of Bhutan (NEC, 2011). The latter two gases were converted to CO_2 equivalent using the 100-year global warming potential. The LEAP model calculates the GHG at sector level, based on the energy demand projected for each economic sector. The energy demand projections were linked to population, number of households and GDP. The ImPACT model, which becomes the Kaya Identity (Kaya, 1990) when dealing with GHG emissions (discussed in section 2.6, Chapter 2), forms the basis for calculation of GHG emissions for the Bhutan–LEAP modelling.

The modelling undertaken in Publication 5 provides an explanation of the comprehensive energy–economic transformation for carbon neutral Bhutan through seven distinct scenarios, focused on economic growth patterns: 1. Business-As-Usual (BAU), 2. High economic growth –represented by high gross domestic product (HGDP), 3. Low economic growth – represented by low GDP (LGDP), 4. NDCPlan. – representing Bhutan's nationally determined contribution plan. Each of these scenarios, apart from LGDP, has their carbon neutral counterpart to contain the emissions below the sink capacity of 6.3 MT of CO_2eq. The NDCPlan scenario captured and quantified four of the nine 'identified priorities' outlined in Bhutan's NDC.

Publication 4 used the same baseline data sets as Publication 5, but investigates Bhutan's contribution to the 1.5°C agenda of the IPCC through plausible scenarios that capture some elements of GNH strategy to incorporate sufficiency thinking (Samadi et al., 2017) and the structural shift towards a knowledge-based urban society. Publications 4 and 5 focus on economy-wide national emissions and show how the integration of GHG, GDP and GNH has been attempted as the basis of generating policy scenarios. Further modelling and analysis conducted within this exegesis (see Section 5.4) used per capita energy consumption and emissions in Bhutan and compared these to the low carbon criteria of 3.5t CO_2/capita and life expectancy over 70 years, known as the Goldemberg Corner (GC) (Lamb, 2016; Lamb et al., 2014) and an additional criteria of final energy consumption at 45 GJ per capita for a high human development index (HDI) of 0.8 (Costa et al., 2011). HDI is a "summary measure of average achievement in key dimensions of human development"[4]. This was undertaken to examine whether the case of carbon neutral Bhutan also aligns with the low carbon criteria under the Goldemberg Corner.

[4] See http://hdr.undp.org/en/content/human-development-index-hdi

3.2.2 Regression analysis

Regression analysis is an econometric technique widely used for forecasting, as well as to examine the relationship between variables of interest relevant to the topic under investigation (Gujarati, 2011). Econometrics is a subfield of economics that deals with data analysis and interpretation of the relationship between economic variables (Gujarati, 2011). Regression analysis appears to be ubiquitous in many disciplines, given its data-driven analytical approach (Dasgupta & De Cian, 2018; Gujarati, 2011; Zhang, Z. et al., 2018).

This thesis used EViews, an econometric tool used for regression analysis (Gujarati, 2011; IHS Global, 2014; Zang et al., 2018; Zbuchea, Pînzaru, Busu, Stan, & Bârgăoanu, 2019), to conduct multivariate regression analysis on 33 years of time series data on four variables: per capita CO_2 emissions, per capita GDP, population and life expectancy (as a proxy variable for human wellbeing). The independent variables in the regression model are the quadratic and cubic terms of the per capita GDP and population. The variables were related using the following functional form:

$$lnCIWB = C+\beta_1(lnGDPpc)^2+\beta_2(lnGDPpc)^3+ \beta_3 lnPOP+ \beta_4 lnCIWB\ (-1)+\varepsilon_t$$

The functional form was arrived at based on model selection criteria such as goodness of fit, standard error of regression and Akaike information criterion, and other necessary statistical tests. See Publication 3 for further details. Those data were collected from reliable, publicly available, international sources, such as the World Bank (2017). Both the Ordinary Least Square (OLS) and Robust Least Square (RLS) estimation methods were used (see Publication 3). OLS is a widely used estimation technique in regression analysis that essentially minimises the sum of the squares of the error term; whereas RLS is specifically used when there are data/observation outliers in the sample of variables chosen to examine the issues of interest (IHS Global, 2014). This quantitative method provides a data-driven analysis of Bhutan's economic growth and carbon intensity of human wellbeing (Jorgenson & Givens, 2015; Sweidan, 2018) and their relationship in the framework of the Environmental Kuznets Curve (EKC) (discussed in section 2.7, Chapter 2 and Publication 3), which substantiates the confounding debate on the environmental impact of economic growth.

3.3 Qualitative research methods

3.3.1 Semi-structured interviews and analysis

Turner (2010) identifies interviews as a qualitative research method that can reveal in-depth information about the experiences and viewpoints of an interviewee on a chosen topic. Semi-structured interviews, besides being popular in social science and health studies, have also been used to study a range of topics in the field of energy and environment (Bolton & Foxon, 2015; Butterworth, Subramaniam, & Phang, 2015; Zimmer, Jakob, & Steckel, 2015).

This research used semi-structured interviews conducted with key stakeholders in Bhutan to help uncover the inside story of Bhutan's current status and future challenges. The majority of the participants were from Bhutan government agencies concerned with environmental issues, energy policy and national planning; others were from non-governmental international agencies concerned with Bhutan's development issues (see Publication 2).

A total of 25 potential participants were initially identified to be interviewed; a total of 19 people were contacted; and a total of 16 people participated in the interviews. Important viewpoints may have been missed by not being able to conduct interviews with all the potential participants.

NVivo11, a widely used computer aided qualitative data analysis tool developed by QSR International (Leech & Onwuegbuzie, 2011), was used to organise and analyse the interviews. A thematic analysis of the semi-structured interviews was undertaken to draw key messages. Thematic analysis is a flexible and widely used qualitative data analysis method, which can reveal issues and problems pertaining to the topic under investigation (Hawkins, 2017). Twelve thematic areas were formulated as shown in Table *1* that have a bearing on the carbon neutral pledge of Bhutan (see Publication 2).

Table 1. Thematic areas for interview analysis

Sl#	Themes
1	Policy frameworks
2	Institutional issues
3	Human resource and climate financing issues
4	Planning tools and the GNH policy screening tool

5	Topography and urbanization
6	Transport and industry sector
7	Transitioning economy
8	Role of, and issues with, hydropower
9	Conflict with ecotourism
10	Forest cover and carbon accounting issues
11	Climate change impacts
12	Other issues

3.3.2 Literature Synthesis and conceptual framework

A broad qualitative comparison between the 17 SDGs and the nine domains and 33 indicators of Bhutan's GNH was undertaken to help explain the implications and synergies between the two different frameworks. Alongside this comparison, how and where the carbon neutral pledge of Bhutan fits into these two agenda were presented. Drawing inferences from these analyses and supplemented by the existing literature on sustainability, wellbeing and low carbon development, a 3G model of Bhutan, comprising GNH, GHG and GDP, was conceptualised and introduced to strengthen Bhutan's contribution to the sustainability discourse (see Publication 1).

3.4 Data collection and data availability

For the energy–economy modelling, collection of national-level-specific data for techno-economic parameters posed a daunting task. Where no national data existed, data was gathered from the wider literature and imputed and adapted, with consequent implications for the model results. Wherever possible, data from neighbouring countries to Bhutan, such as India and Nepal, were used.

For the regression analysis undertaken in Publication 3, time-series data during the period 1980 to 2012 for population, GDP and CO_2 equivalent emissions, were sourced from the open knowledge database of the World Bank (2017). Data for emissions were found to have outliers at five different points, especially 1999. Beyond these data issues, the limitations of the methods employed in this research are highlighted below.

3.5 Limitations of the methods

Quantitative modelling is considered to be less suited to capturing socio-technical dynamics and multi-actor interactions (Geels et al., 2016; Geels et al., 2017; Lamb & Steinberger, 2017). However, more recently, proponents have expanded energy modelling to incorporate social issues and shared human development (Nakata et al., 2011; Nilsson et al., 2012) and relate energy–economic issues to sustainable development (Ouedraogo, 2017). This allows for a broader set of characteristics to be captured. The advantage of modelling is its ability to provide a data-driven picture of the entire energy system, in this case Bhutan, thus enabling its suitability for policy analysis.

LEAP model, which is a simulation model, gives sufficient flexibility to the modeller to incorporate policy-oriented parameterisation and subsequent scenario building (Ouedraogo, 2017; Urban, 2009). However, inherent limitations remain. For example, any model is a miniature representation of the real world, and modelling inevitably requires assumptions to be made (Nakata et al., 2011; Rogelj et al., 2018), which has implications on the results of this research and subsequent inferences. Moreover, the LEAP model is limited because it is not a climate science model, even though it is being widely used for developing low emissions strategy suitable for policy analysis (Kumar & Madlener, 2016; Nilsson et al., 2012; Shakya, 2016; Urban, 2009; Yang, D. et al., 2017) (see Publications 4 and 5).

Similarly, the regression analysis used in Publication 3 also has limitations. Some of these limitations include the quality and quantity of data representing the variables of interest for the issues under investigation. The accuracy of the results always depends on the accuracy of the data inputs. See section 3.4 on issues relating to data collection and availability.

There are also potential limitations in relation to the interviews conducted. For example, the sampling approach used, which focused on purposely identifying key stakeholders working in government agencies and international organisations, did not involve the general public or civil societies, who could have quite different viewpoints. However, the aim was not to analyse representative viewpoints, but to garner an in-depth information from the policy stakeholders on challenges and opportunities for sustaining the carbon neutral policy.

Considering that there is always a compromise between breadth and depth of covering earlier works (Dasgupta & De Cian, 2018), literature that focused exclusively on happiness or human wellbeing without relating to environmental issues such as carbon or GHG emissions were not reviewed in Publication 1. It undertook a synthesis of the literature alongside the three goals of Bhutan that has ultimately informed the development of Bhutan's 3G model. Further details of the limitations of the methods employed in this research are outlined in each of the five publications.

Chapter 4 Overview of publications

This chapter provides a summary of each publication submitted, which can be found in full appended to the exegesis. Each publication answers aspects of different sub-questions of this thesis as outlined in Figure 7.

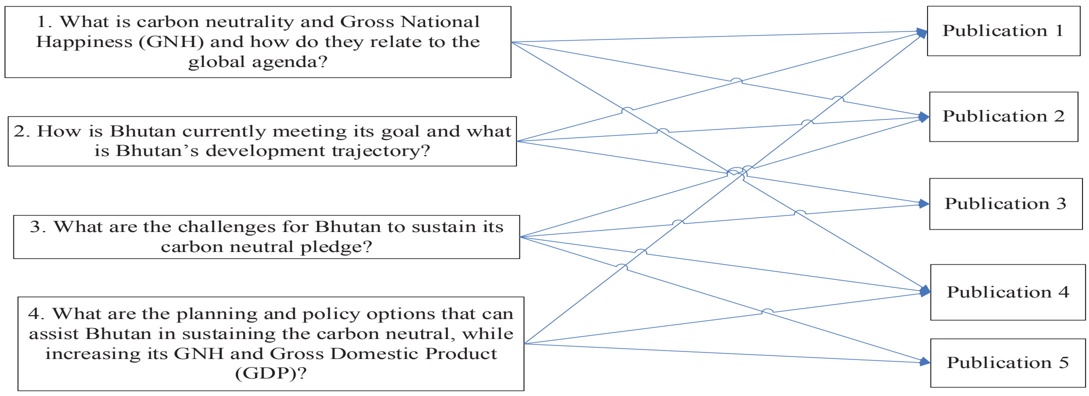

Figure 7. Cross-linkages between sub-questions and the five publications

4.1 Publication 1

Yangka, D., Newman, P., Rauland, V., & Devereux, P. (2018). Sustainability in an emerging nation: The Bhutan case study. *Sustainability, 10*(5), 1622.

Paper abstract

With the onset of the 17 Sustainable Development Goals (SDGs) and the Paris Agreement on Climate Change, the world's nations were set to create economic development integrating environmental and social improvement. However, there is still much uncertainty in the world of politics and academia as to whether these integrated goals are achievable and how they can fit best with diverse national and local contexts. Thus, there is always a need to find nations that can show how it can be achieved in different settings shaped by local experiences, challenges and opportunities. Bhutan could be one of these nations as it could be argued that it has, to an extent, simplified the task to fit its values and aspirations. Bhutan has three major goals that need to be integrated: Wealth (GDP) to align with their middle-income aspirations, thus providing opportunities for employment; Greenhouse Gas emissions (GHG) that are maintained at a carbon neutral level, which is beyond most national commitments; and Bhutan's renowned Gross National Happiness (GNH) index, which

relates to the country's socio-economic goals. We show this integration and then synthesise some core findings from a literature review on the theory and practice of sustainable development through the lens of the three integrated goals of Bhutan, thereby placing the case of Bhutan into the wider literature. This paper seeks to show how one emerging nation can model an operational sustainability policy. The paper highlights some plausible synergies between the 17 SDGs and the domains and indicators of GNH that could help nations struggling with how they can create sensible sustainability outcomes from these new global agendas. Bhutan has framed the GNH as its contribution to sustainability. However, this paper suggests that it may be the integration of the GNH with GDP and GHG that is its real contribution. Furthermore, Bhutan's 3G model of fully integrating GNH, GDP and GHG suggests a way forward for achieving their imperatives of economic growth, while enabling the SDGs and achieving the difficult climate change goal. It may also suggest a model for other nations wanting to find a complementary way of framing economic growth, the 17 SDGs, and the Paris Agreement into a coherent set of policies.

4.2 Publication 2

Yangka, D., Rauland, V., & Newman, P. (2018). Carbon neutral policy in action: the case of Bhutan. *Climate Policy*, 1–16.

Paper abstract

Climate policy across the world is proceeding at a highly variable pace, with some countries deeply committed to decarbonising their economies and others just beginning. Emerging nations are generally just starting along this journey. However, among the few nation-states that have pledged to achieve carbon neutrality, is Bhutan, one of the world's least developed country. Carbon neutrality is an ambitious climate policy that is increasingly being recognised as necessary in order to stabilise global temperature rise at 1.5°C. However, Bhutan is likely to face significant challenges in maintaining this status as the country balances its desire to grow in economic opportunities (GDP) and in human happiness (GNH). Little research has been conducted on the policy processes to better understand how Bhutan will maintain carbon neutrality. Through open-ended, semi-structured interviews with key stakeholders, this study provides an inside view on the current situation and future challenges that Bhutan may face, along with the complexities associated with implementing and maintaining an ambitious carbon neutral policy. The paper highlights Bhutan's story and how it could be useful for policy learning and knowledge sharing, especially in the context of emerging nations' climate governance.

4.3 Publication 3

Yangka, D., Rauland, V., Newman, P., (2019). Happiness, environment and wealth: What can Bhutan show us about resolving the nexus? Modern Economy *(accepted)*.

Paper abstract

The Environmental Kuznets Curve hypothesis examines how economic development can improve environmental outcomes (known as Modernisation theory) or cause worse outcomes (known as the Treadmill of Production theory). This paper examines Bhutan, which has committed policies for increased happiness and wealth while remaining carbon neutral. The difference is being tested by regression analysis of how economic growth varies with the environmental intensity of wellbeing (EIWB). The regression analysis shows that the case of Bhutan can be explained in terms of the Treadmill of Production theory based on economic and wellbeing growth harming the environment; however, it is simply too early in the EKC to come to conclusions. The data also shows that population growth helps resolve the nexus, which aligns more with the Modernisation theory perspective and supports the need to continue the move to urbanisation to resolve these issues. Rather than just simply waiting for economic growth to turn around the EKC, Bhutan should take direct action to maintain its carbon neutral goal and its happiness goal and thus continue to provide a model for the sustainable development discourse in general.

4.4 Publication 4

Yangka, D., & Newman, P. (2018). Bhutan: Can the 1.5 °C agenda be integrated with growth in wealth and happiness? *Urban Planning, 3*(2), 94–112. doi: 10.17645/up.v3i2.1250

Paper abstract

Bhutan is a tiny kingdom nestled in the fragile ecosystem of the Eastern Himalayan range, with urbanisation expanding at a rapid rate. To the global community, Bhutan is known for its Gross National Happiness (GNH) index, which in many ways is an

expression of the Sustainable Development concept. Bhutan is less known for its policy of being carbon neutral, which has been in place since the 15th session of the Conference of Parties meeting in 2009 and was reiterated in their Nationally Determined Contribution with the Paris Agreement. Bhutan largely achieves its carbon neutral status through its hydropower and forest cover. Like most emerging countries, Bhutan wants to increase its wealth and become a middle-income country by 2020, as well as increase its GNH. This study looks at the planning options to integrate the three core national goals of GNH, economic growth (GDP) and greenhouse gas (GHG). We investigate whether Bhutan can contribute to the 1.5°C agenda through its 'zero carbon commitment', as well as growing in GDP and improving GNH. Using the Long-range Energy Alternatives Planning (LEAP) model, this paper shows that carbon neutral status would be broken by 2037 or 2044 under a high GDP economic outlook, as well as a business as usual scenario. National and urban policy interventions are thus required to maintain carbon neutral status. Key areas of transport and industry are examined under two alternative scenarios and these are feasible to integrate the three goals of GHG, GDP and GNH. Power can be kept carbon neutral relatively easily through modest increases in hydropower. The biggest issue is electrification of the transport system and plans are being developed to electrify both freight and passenger transport.

4.5 Publication 5

Yangka, D., Rauland, V., Newman, P. (2018). Carbon neutral Bhutan: sustaining carbon neutral under growth pressures. *(submitted)*.

Paper abstract

Bhutan has pledged to remain carbon neutral (CN) in perpetuity. Whether they can sustain this is questionable due to the country's increasing economic growth (GDP) and commitment to gross national happiness (GNH) outcomes, some of which have led to a rise in greenhouse gas (GHG) emissions. The nexus between GHG, GNH and GDP is the essence of the sustainable development global project. Through scenario modelling using the Long-range Energy Alternatives Planning (LEAP) model, the study finds that the carbon neutral declaration will derail between 2037 and 2050 under different growth scenarios. The options to remain carbon neutral are not beyond Bhutan though, but will require adopting more efficient technologies and electrifying

industry and transport. The additional cost to the Bhutanese economy needs to be part of their economic growth options and are made feasible through growth opportunities. The options are similar to those confronting emerging nations that are struggling with issues of climate commitments along with growth pressures.

Chapter 5 Results and discussion

This chapter provides an integrated discussion of the results from the five publications, along with additional results drawn from the Bhutan–LEAP model. The results are discussed and presented as broad-based themes, addressing several aspects of the sub-questions.

5.1 Challenges to carbon neutral pledge

The global challenge is to stabilise the GHG concentration in the atmosphere to prevent a significant global temperature rise (IPCC, 2014; United Nations, 1992), which will require halving emissions per decade (Rockström et al., 2017) and ultimately net zero emissions (IPCC, 2018; Rogelj, Schaeffer, et al., 2015). Bhutan's challenge and its contribution to the global effort is to sustain its ambitious climate policy of carbon neutrality.

The need to integrate climate policy into national development policies is well recognised (Halsnæs et al., 2007; Halsnæs & Verhagen, 2007; IPCC, 2014; Nishioka, 2016). Taking this framework into consideration, Publication 1 integrates the three core national goals of Bhutan to form a 3G model. It argues that the 3G model strengthens the GNH model by explicitly including GHG (greenhouse gas) and GDP (gross domestic product) as issues for Bhutan to navigate on its carbon neutral journey while it becomes a middle-income country. There is an inherent risk that one of them may falter – given that the environmental impact of economic growth is still often contested, as seen in literature around the Environmental Kuznets Curve (EKC) hypothesis (Grossman & Krueger, 1995; Panayotou, 1993; Rashid Gill, Viswanathan, & Hassan, 2018; Song, Zheng, & Tong, 2008; Stern, D. I., 2004). Some of the apparent risks were exposed through the semi-structured interviews conducted with the key stakeholders of Bhutan (see Publication 2). The interviews revealed divergent views from participants on how to sustain Bhutan's long-term carbon neutral pledge (see Table 2 in Publication 2). Within those divergent views, there was a tone of complacency and much optimism among the stakeholders, which could downplay the risks or challenges, and thus the need for strong policy intervention. Surprisingly, the impact of rapid urbanisation was also contested (see Publication 2), with some seeing advantages, and others, challenges. Notwithstanding this, a scenario for a knowledge-based society was found to be capable of keeping emissions below the sink capacity, as Bhutan urbanises and aspires for high economic growth. The knowledge-based society envisages a high level of urbanisation, aggressive deployment of low carbon transport, high economic growth with the service sector contributing a larger share to the national GDP (see Publication 4 for details). This concurs with literature that suggests combining knowledge cities with low carbon urban development (Glazebrook & Newman, 2018; Wang, C. et al., 2018). It should be noted that the GNH index includes the pros and cons of urbanisation through its 'urban issues' indicator that captures congestion and urban sprawl among other issues.

Aside from urbanisation, not surprisingly, the need for financial support emerges as a key challenge and many of the stakeholders who participated in the interviews (see Publication 2) argued that having the required level of financial support can leverage technological and human resource constraints. These techno-economic challenges are illustrated by the Bhutan–LEAP model (see Publications 4 and 5). It calls for additional funding that could potentially compete with the budget for other development activities. For example, aspiration for high economic growth (without low carbon interventions) is expected to cause additional cumulative emissions of 55 million tons of CO_2eq during the period 2014 to 2050. To reduce these emissions in order to retain its carbon neutrality, Bhutan has to bear a mitigation cost of \$37.93/tCO_2eq. This quantifies the challenges surrounding the need for financial support to prevent such a scenario from unfolding. Such challenges were also noted by the World Bank in their report on decarbonising development (Fay et al., 2015).

The biggest challenge is emission levels exceeding the sink capacity (see Publications 4 and 5), which appear likely without significant policy interventions, suggesting that there is no room for the complacency demonstrated in the interviews with the key stakeholders (see Publication 2). The results from the energy-economy modelling undertaken in Publication 5 is shown in Figure 8 for the business-as-usual (BAU) pathway, demonstrating that emissions will exceed the sink capacity by 2044.

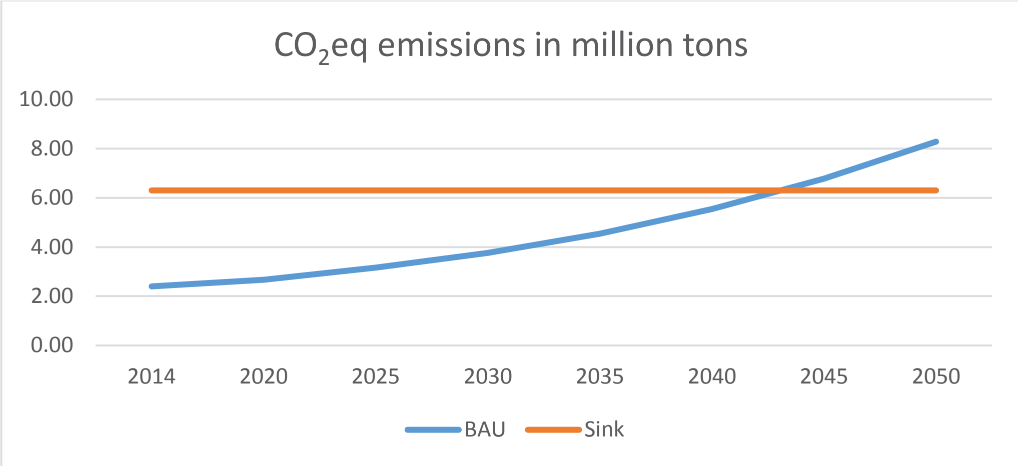

Figure 8. Total CO_2eq emissions under BAU scenario

An expanded version of this graph appears in Publication 4 (Figure 4) and Publication 5 (see Figure 4a, b and c) showing the emissions level under various scenarios. The need for structural changes is evident from the model results. For example, the carbon neutral measures for the BAU scenario presented in Publication 5, did not include a shift from the industry sector to the service sector, and as a result incurs a mitigation cost of \$2.07/tCO_2eq. Whereas, the scenario showing a structural shift, presented in Publication 4, leads to a cost *saving* of \$15.05/tCO_2eq. This is a major policy insight, considering that Bhutan currently completely relies on its forest sink capacity. Furthermore, carbon accounting around forest sequestration is uncertain, and it is highly contested in the literature (Bääckstrand & Löövbrand, 2006; van Kooten, 2017) (see Publication 2). To avoid accumulation of carbon-intensive assets and infrastructure, Bhutan would need to update its carbon neutral strategy on a regular basis. Literature on decarbonisation recommends undertaking such an update once every two years considering rapid technological innovation (Rockström et al., 2017).

The regression analysis undertaken in Publication 3 also indicates that carbon emissions will increase with economic growth, without low carbon interventions, and that there exists a curvilinear relationship between them. This supports the modelling results, and Bhutan's concern as noted in its National Human Development report (GNHC, 2011) concerning its ability to maintain its carbon neutral goal while growing its economy. This is likely to be a serious challenge for Bhutan as it aspires to be a middle-income and self-sufficient country (RGoB, 2016). Despite these challenges, there are a number of opportunities, including technological pathways that will aid Bhutan in maintaining their CN pledge.

The next section discusses the planning options and specific factors that will assist Bhutan in remaining carbon neutral.

5.2 Factors leveraging the current status of Bhutan's carbon neutral pledge

There are many factors that will affect whether Bhutan is able to maintain its carbon neutral goal. While forest cover is currently considered to be the cornerstone for providing a carbon sink, results from energy modelling (Publication 4 & 5), as well as the interviews (Publication 2), demonstrate that hydropower will also play a continuing, and increasingly important, role by avoiding emissions from electricity (see Publications 4 and 5). The literature highlights the importance of energy systems being electrified to a greater extent, and underpinned by low carbon technologies such as hydropower (Fankhauser, 2013; Fay et al., 2015; Rockström et al., 2017; Wei et al., 2013), to deliver high economic and societal goals. Therefore, if Bhutan's hydroelectric power grows in line with its economic growth, it will avoid the costly decarbonisation of its electricity system, i.e. through switching technology and/or fuel, which will be required by many other countries wanting to reduce emissions. While electricity can be hydropower-based, technological changes will be an imperative in most of the economics sector. Residential and commercial sectors will have to shift towards electric appliances, manufacturing industries will have to pursue energy efficiency and industrial symbiosis, and transport will require massive uptake of electric vehicles and light rail. This needs to be accelerated if Bhutan wants to pursue high economic growth (see Publications 4 and 5).

Beyond the techno-economic opportunities, there are socio-cultural patterns that can also help to sustain the carbon neutral pledge. Bhutan's GNH strategy and its pro-environmental constitution promote carbon neutral pathways (see Publications 1 and 2), which are the unique internal determinants that help to uphold an ambitious climate policy for such a tiny developing nation-state. Findings from a pilot study on GNH in business at a luxury tourist hotel in Bhutan revealed that instilling the principles of GNH into a business enables sustainable practices –low consumption and low emissions (RGoB, 2012a). These are possibly the socio-institutional pre-conditions that will aid their national carbon neutral policy, and are different from those factors outlined in earlier research relating to what makes a nation pledge for carbon neutrality (Flagg, 2015). Social capital is said to be the key to sustainability (Knight & Rosa, 2011) and human wellbeing (Smith, L. M., Case, Smith, Harwell, & Summers, 2013;

Vemuri & Costanza, 2006), especially during times of economic crises (European Policy Centre, 2011). For Bhutan, this social capital is captured by community vitality, and cultural diversity and resilience - two of the nine domains of GNH strategy that remain high as per the GNH survey reports (CBS, 2012, 2016). Furthermore, the graphical representation of the 'scope of happiness' in Bhutan (see Figure 4 in Chapter 2) also clearly shows that such social capital in the form of family and community relationship is highly embedded in the daily routines of the Bhutanese. The aforementioned factors, such as forest cover and hydropower, and socio-cultural variables, thus enable and support the current carbon neutral status of Bhutan.

Surprisingly, the regression analysis shows that increasing population will have a decreasing effect on the carbon intensity of human wellbeing (see Publication 3). This is naturally a desirable phenomenon for long-term carbon neutrality, although it is likely to be met with contention from some academics and policy-makers though those who see growth as creating potential change for sustainability outcomes will see this as supportive of their theories (Hatfield-Dodds et al., 2017; IRP, 2017; Newman, 2011). Regardless, population increase is unlikely to be a cause for concern for Bhutan, at least for the time being, as there are currently less than 750,000 people (NSB, 2018).

5.3 Wellbeing and carbon neutrality

Alternative scenarios in the Bhutan–LEAP model incorporate several emissions reduction measures that also provide social benefits. For example, health benefits from better air quality from replacing kerosene- and fuelwood-based cooking and heating with electric options, providing electric automobiles, buses and trucks, implementing light-rail transport and encouraging walking through better urban design (Glazebrook & Newman, 2018; Newman, 2015; Newman & Kenworthy, 2015). An electric public transport system and encouraging walking (active transport) reduces emissions and improves air quality, and enhances health and social capital through increasing the chances of social networking (Hiscock et al., 2014). Publication 4 captures some elements of the GNH strategy, which also reduce emissions. The combination of strategies raises Bhutan's contribution to the global agenda of the Paris Agreement and Sustainable Development Goals.

Spending time in nature and having green space were associated with a higher level of wellbeing (Hiscock et al., 2017; Smith, L. M. et al., 2013). Forest cover – the natural green space – could therefore be indirectly enhancing human wellbeing for many rural communities in Bhutan, as well as providing a source of livelihood. It is self-evident that without a sustainable livelihood, wellbeing is hard to achieve. The living standard domain of GNH includes income, assets (comprised of household appliances, livestock and land) and housing conditions to assess comfortable living in the context of Bhutan (CBS, 2012). But living standards, regardless of the level, causes potential environmental stress, such as emissions and waste which can be mitigated as economic development occurs as suggested by the EKC theory. This led Rao and Baer (2012) to propose 'decent living emissions' for developing countries, which should be taken into account when considering global carbon budgets.

Similarly, others (Costa et al., 2011) have proposed a Human Development Index (HDI) value of 0.8 as a cut-off point for development emissions for emerging economies (that is - these countries can increase emissions to this point) and emissions reduction for developed countries that have HDI values above 0.8, thus providing an equitable carbon budget for all. Thus there are contentious issues about well-being and carbon neutrality that need to be analysed and the scenario modelling was designed to help with this.

The next section discusses if the per capita carbon emissions and energy demand in Bhutan fulfils this condition without breaching the carbon neutral budget.

5.4 Energy and emissions for human wellbeing

Publications 4 and 5 address the issues of growth and development. Additional results from the Bhutan–LEAP model are provided here to further strengthen the arguments made in the five publications, as well as to maximise the utility of the Bhutan–LEAP model. These additional results relate to per capita energy and emissions derived from the economy-wide perspectives presented in Publications 4 and 5.

Globally, per capita energy demand has increased substantially – from 18.34 GJ/capita/year for a person using primitive agriculture to 305.65 GJ/capita/year for those with more technological lifestyles (Goldemberg, 2012).[5] This demonstrates that modernisation has always triggered more energy consumption and will need to change in the future if the world is to adapt better to living on this earth. The final

[5] Original figures in kilocalories (kcal) were converted to gigajoule (GJ) using conversion factor of 1 Gcal = 4.187 GJ.

energy requirement of 30 GJ/capita was found to meet basic human needs (Lamb & Rao, 2015; Lamb & Steinberger, 2017) and to maintain a high human development index (HDI) of 0.8 was shown to gradually decrease from 60 GJ/capita in 2005 to 45 GJ/capita by 2030 (Steinberger & Roberts, 2010). This suggest that human development can be decoupled from energy requirement and that energy consumed with a technological lifestyle is too high. Nonetheless, at the global level, final energy consumption stands at 53.39 GJ/capita in 2016 with OECD countries consuming more than double of this amount (IEA, 2018).[6] For Bhutan, the amount of per capita final energy consumption, which includes final energy consumption for household activities (e.g. cooking, heating and lighting) and transportation, are shown in Table *2* for three selected scenarios: Business-As-Usual (BAU), high economic growth (HGDP) and the carbon neutral counterpart of HGDP (CNHGDP).

Table 2. Final energy consumption under selected scenarios (GJ/capita)

Scenarios	*2014*	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
BAU	18.90	19.43	21.62	24.41	27.88	32.09	37.09	42.86
HGDP	18.90	19.91	23.58	28.86	35.89	44.84	56.64	72.81
CNHGDP	18.90	17.02	17.47	18.36	21.92	25.47	29.07	32.76

The HGDP and its carbon neutral counterpart were selected because HGDP represents the most challenging scenario in terms of higher CO_2eq emissions associated with energy requirements, as per the ImPACT identity (see Chapter 2 for details).

The per capita energy demand under BAU and CNHGDP remain within the requirement for high HDI during the entire planning period. However, it should be noted that carbon neutrality is sustained *only* under the CNHGDP scenario (see Figure 4(c) in Publication 5). This demonstrates that higher human development can be achieved without higher energy consumption under Bhutan’s carbon neutral policy. This is made possible by fuel-switching and adopting more efficient technologies, demonstrating that green growth has a critical role to play as Bhutan embarks on the journey to achieve middle-income status. It also indicates that part of GNH is being fulfilled, given that the components of HDI, such as income, health and education, also

[6] Converted to GJ based on 9555 Mtoe and 7492 million population provided in IEA.

form some of the critical, tangible elements that improved the GNH index between 2010 and 2015 (CBS, 2016). It should also be acknowledged that the HDI is less multidimensional than the GNH index, and that this research does not mean to conflate HDI with GNH. What is of note is that such benchmarking can also inform the need for a Sufficiency threshold for energy consumption in Bhutan, which is not yet reflected in the GNH index.

Whether per capita emission levels can remain within the low carbon development criteria suggested in the literature is discussed below. Table 3 shows the per capita CO_2eq emissions for Bhutan under the three selected scenarios: BAU, HGDP and CNHGDP. The existing literature categorises 20 nations as 'virtuous', fulfilling the Goldemberg Corner (GC) – 3.5tCO_2/capita and life expectancy of more than 70 years (Lamb, 2016). Up until now, life expectancy in Bhutan has been lower than that specified under the GC criteria. It has steadily increased from a pitiful 47.4 years in 1984 (RGoB, 2000) to 70.6 years in 2017 (UNDP, 2018). As can be seen in Table 3, per capita CO_2eq emissions will pass the GC criteria by 2025 under BAU and HGDP scenarios, but remain within the GC criteria until 2030 under the CNHGDP scenario. Beyond 2030, the GC criteria will be breached (i.e. per capita emissions are more than 3.5 tCO_2/capita), although national carbon neutrality will be sustained. In 2014, at the global level, average per capita CO_2 emissions was 4.47 tonnes (IEA, 2016) and 4.35 tonnes in 2016, compared to levels ranging from 0.95 for Africa to 9.02 for OECD (IEA, 2018). This shows that the per capita emissions in Bhutan, even in 2050, will still be far lower than the OECD countries' 2016 levels.

Table 3. CO_2eq missions under selected scenarios (tCO_2eq /capita)

Scenarios	2014	2020	2025	2030	2035	2040	2045	2050
BAU	3.22	3.35	3.73	4.24	4.84	5.58	6.46	7.49
HGDP	3.22	3.43	4.06	4.98	6.19	7.75	9.80	12.61
CNHGDP	3.22	3.13	3.38	3.28	3.75	4.24	4.78	5.40

Tables 2 and 3 clearly demonstrate that carbon neutral status can be sustained under a green growth-based high economic pathway, while also meeting the low carbon development criteria under the Goldemberg Corner until 2030, the end period of the global SDGs. This is also an example of how the complex interplay between the three goals of Bhutan could be reaped to their advantage.

From the discussions above and those in section 2.11, it appears that an integrated framework is required to capture the complexities of sustaining carbon neutrality in a growing economy, while increasing GNH.

5.5 Creation of an integrated framework

The analysis above suggests that economic growth is essential to improving liveability and reducing social problems, while a reliable, affordable and sustainable energy system is an imperative to mitigate emissions. Clearly, transitioning to new low carbon technologies and infrastructure systems can help to provide the economic opportunities needed. This is also evident from the global effort to move from the millennium development goals (MDG) to the SDGs (Halisçelik & Soytas, 2018; Sachs, 2012), along with meeting the UNFCCC's Paris Agreement, which requires substantial emissions reduction (UNFCCC, 2016). Earlier works showed that low carbon development pathways can be pro-poor along with being climate benign (Colenbrander et al., 2016; Shakya, 2016; Urban, 2010).

Globally, decoupling economic growth and emissions are seen to be occurring (Newman, 2017; Schandl et al., 2016). Wu, Zhu, and Zhu (2018) found that the decoupling trend between energy and economic growth is greater in developed countries than in the developing countries, due to there being more opportunities for technical progress and structural changes, including greater ability to finance changes. Absolute decoupling of energy (including energy embodied in trade) from human development was found in 27 countries out of 126 between 2000 and 2014, but the number reduces to 6 when considering human development index above 0.8 (Akizu-Gardoki et al., 2018). Thus, Akizu-Gardoki et al. (2018) argue that decoupling is achievable, but much work needs to be done for it to be successful. The Bhutan–LEAP modelling illustrated that Bhutan can pursue high economic growth and stay within its carbon neutral budget if fuel switching and greater adoption of efficient technologies (a decoupling phenomenon) are undertaken – notably in the transport and industry sectors. Advocates of the Ecological Modernisation theory believe that structural changes and technological innovation are needed to propel the decoupling phenomenon (see section 2.7, chapter 2).

The regression analysis undertaken in Publication 3 shows that economic growth increases the carbon intensity of human wellbeing, which aligns with the Treadmill of

Production theory. However, a simple graphical plot between GDP and CO_2eq emissions reveals evidence of relative decoupling during the period between 1980 and 2012, indicating that emissions are growing at a slower pace than economic growth. Furthermore, countries focused on wellbeing appear to have more options to promote a decoupling agenda (UNEP, 2014). This suggests the need for the Sufficiency element, especially beyond the saturation point in the income–wellbeing relationship. Sufficiency is highly visible in Bhutan's GNH philosophy, which sets a sufficiency cut-off level to calculate the GNH index (CBS, 2016; Hayden, 2015; Thinley, 2005).

As argued in section 2.9, Chapter 2, happiness under the GNH philosophy can be categorised as a combination of the Folklore theory (Veenhoven & Ehrhardt, 1995) and the Need theory (Gough, 2015), which shares commonalities with the Liveability theory (Veenhoven & Ehrhardt, 1995). The Need theory of Human Wellbeing has an element of sufficiency embedded into its satiation point and it advocates for a wellbeing-based climate policy (Brand-Correa, Martin-Ortega, & Steinberger, 2018; Brand-Correa & Steinberger, 2017; Gough, 2015, 2017; Lamb & Steinberger, 2017). While sufficiency and efficiency may seem incompatible given their diverse conceptual foundation (Alcott, 2008), valuing their complementarity can potentially help to mitigate dangerous climate change and resource depletion, while potentially providing a decent standard of living under the sustainability principle of intra- and intergenerational equity. Thus, it appears that an integrated approach is necessary if Bhutan is to sustain carbon neutrality, while it increases its GNH strategy and economy – the 3G model (see publication 1). This can potentially contribute to achieving a fair living standard that remains within the confines of sustainability (Raworth, 2013).

The attitudes and policy perspectives captured from the interviews with key stakeholders in Publication 2, and the 3G model presented in Publication 1, demonstrate that GNH strategy and carbon neutral policy are compatible and complement each other. Their complex interplay requires an integrated thinking much in line with the Panarchy theory (Holling, 2000) and an integrated thesis (Quental et al., 2011) for operational sustainable development.

5.6 Caveats to the results of this thesis

The scenario-based Bhutan–LEAP modelling shows plausible pathways for carbon neutral Bhutan by taking a forward-looking approach to an uncertain future. Predicting the future is inherently uncertain. But not preparing for it would weaken Bhutan's long-term 3G model and aspiration. As the UNDP (2000) asserts, "the future is much more a matter of choice than destiny". Nonetheless, it would be beneficial if the results were presented to people who pull the policy levers to incorporate their feedback, given that the LEAP model is simulation-based, and ideal for establishing such dialogue (Lund et al., 2017). Given that the interviews in Publication 2 exposed a lack of understanding around future scenarios, especially in the context of interlinkages between the 3Es – energy, environment and economy, this dialogue is critical. Furthermore, acknowledging that many of the socio-technical changes that can support carbon neutrality into the future, modelled in the Bhutan–LEAP model, could be a challenge to implement on the ground, this further strengthens the need for robust discussion. Addressing this issue was outside the scope of this thesis, although the interviews with key stakeholders in Bhutan provided a foundation on which to build the discussion. Considering that the research focuses on macro level analysis, the cost of mitigation and investment requirements were analysed only for the entire economy but not for each specific sector. However, such analysis can be readily undertaken by extracting the required data from the long-term energy-economy model (see Publications 4 and 5). Analysis for each sector could form a separate publication, which can be considered for future work.

Other potential limitations of the research were related to the per capita values discussed in Section 5.4, which are derived from economy-wide figures, and, therefore do not account for distributional issues.

As noted in section 1.5, Chapter 1, this thesis has confined itself to the boundary implied by the definition of carbon neutral held by Bhutan – that is, keeping national emissions within the carbon sequestration capacity of it forest cover.

Chapter 6 Conclusion, policy implications and future research

This thesis has explored the challenges and opportunities for Bhutan to retain carbon neutrality long-term, while also supporting Bhutan's Gross National Happiness (GNH) strategy and aspirations to become a middle-income country (i.e. increasing their GDP). In doing this, the thesis has demonstrated the complex interplay between the three core goals of Bhutan and how these goals demonstrate Bhutan's commitment towards three global agendas, the economic growth agenda set in place for decades with multiple global institutions and agreements, modified recently by environmental and social goals, notably the Paris Agreement, and the Sustainable Development Goals. The following sections outline the key conclusions specific to the four sub-questions asked at the beginning of this thesis.

6.1 How do CN and GNH relate to the global agenda?

Environment is one of the four core pillars within Bhutan's GNH Strategy. Bhutan's CN pledge therefore supports the GNH strategy by strengthening its environmental action through minimising carbon emissions – the largest human environmental impact. Net zero emissions has been identified as the way forward for global climate stabilisation under the Paris Agreement and is now clearly emphasised by the IPCC in its special issue on global warming of 1.5°C. Bhutan's CN policy therefore not only *contributes* to this global agenda, but Bhutan is indeed leading the way for other countries. Bhutan's commitment to CN also addresses the 13th Goal of the 17 Sustainable Development Goals. The GNH strategy, which has strong social indicators, also complement many of the Sustainable Development Goals, which envision a sustainable human society and a safe planet. Thus the papers position these commitments to carbon neutrality and the GNH as being very much global contributions by Bhutan despite it being an emerging nation with a need to become a middle income nation. It therefore sets up the next questions.

6.2 Bhutan's development trajectory and the current status of the three goals

Grappling with the growth objectives and how they relate to CN and the SDG's required qualitative and quantitative analysis. Applying the concept of carbon intensity of human wellbeing (CIWB) to data from the past 33 years reveals a curvilinear relationship between CIWB and economic growth, and supports the Treadmill of Production theory. This demonstrates that sustaining the goal of carbon neutrality within a growing economy will be a challenge following the past development trajectory. This also implies that aspirations for a middle-income country will test Bhutan's bold declaration of carbon neutrality. However, the relationship between CIWB and population leans toward Modernisation theory, suggesting that population need not be a cause for concern for Bhutan's carbon neutrality, and the decoupling of economic growth from GHG suggests that GDP can be modified rather than removed from policy scenarios. The mixed results demonstrate the complexity of resolving the heated debate between these two dominant environmental impact theories.

Until now Bhutan has not transgressed its carbon neutral budget of 6.3MT, while their GNH index increased by 1.8% between 2010 and 2015. The base year of the Bhutan–LEAP model (2014) had total CO_2 equivalent emissions of 2.4 MT against the forest-based sink capacity of 6.3 MT. This budget has not yet been tested, as Bhutan is at an early stage of economic development, usually associated with lower emissions levels. However, the Business-As-Usual trajectory into the 2050 planning horizon demonstrates the likelihood of CN status being breached by 2044. Nonetheless, this research has demonstrated the opportunities for Bhutan to remain within the budget into the future. The country's admirable forest cover and hydropower-based electricity system, in the first instance, provides significant resource advantages for its carbon neutral goal. Bhutan's pro-environmental Constitution and its GNH strategy also provide a formidable policy framework within which to retain its carbon neutrality. This demonstrates that a precautionary-based policymaking approach does assist in supporting socio-environmental sustainability. The thesis has also shown the necessary policy options and trajectories that will be needed in industry, urban planning and transport (see 6.4 and 6.5) to enable the nexus between GDP, GNH and GHG to be resolved.

6.3 What are the challenges and opportunities for Bhutan to sustain its carbon neutral pledge?

Sustaining Bhutan's carbon neutral pledge will become more challenging in the coming decades as the country develops its economy from a low base. This research demonstrates the likelihood of Bhutan breaching its carbon neutral pledge as early as 2037 under the high economic outlook, or 2044 under BAU, which highlights challenges that need to be addressed. This is significant considering that Bhutan aspires for high economic growth to enable it to become a middle-income nation by 2023.This aspiration, without low carbon interventions, is likely to threaten its carbon neutral goal. To this end, the Bhutan–LEAP model shows that the high economic outlook to maintain the carbon neutral goal will require changes to the transport and industrial systems. There is a need to increase the share of electric transport within the system to remove the oil dependence and enable transport to be zero carbon, as it will run on hydroelectricity. The other area of change is the industrial symbiosis with efficiency improvement in the industry sector, switching to electricity wherever possible and using primarily electric goods in the residential sector to provide energy services. These will all enhance liveability commensurate with socio-economic conditions under a middle-income level and consistent with fairness and sufficiency elements of GNH. These mitigation measures will cost Bhutan 2% of its annual economic output, averaged over the planning period between 2014 and 2050.

Besides the techno-economic challenges, this thesis has shown that complacency and much optimism were apparent among the key stakeholders in Bhutan, who pull the policy levers. This could possibly downplay the need for stronger policy interventions to retain carbon neutrality in the long term, especially on Bhutan's pathway towards being a middle-income country. Furthermore, divergent viewpoints are emerging among the stakeholders that will require consistent collaboration to bridge the siloed sectoral level solutions.

6.4 What are the planning and policy options that can assist Bhutan in sustaining the CN pledge, while increasing GDP and GNH?

As nations continue to urbanise and grow their economies into the future, designing low carbon cities and managing their growth will determine the future for human society. Considering this global phenomenon, this research has demonstrated the need for national planning for a knowledge-based urban society to cope with the increasing growth pressures, in order to remain carbon neutral. The Bhutan–LEAP model established a basis for continuing long-term energy–climate policy analysis. Furthermore, the Bhutan–LEAP model can be used to further explore sectoral level data, as well as end-use level data around policymaking and implementation. Complementing the techno-economic opportunities, the sufficiency-based and nature-oriented development strategy of Bhutan has significant influence on its development plans, and appears to contain the unique institutional pre-conditions that pave the way for a low carbon, happy nation.

The country is also likely to benefit from its citizens maintaining their Buddhist belief of sufficiency and their symbiotic relation with nature. This belief in sufficiency, which invokes a threshold setting for the GNH index, and also promotes sustainable consumption, is beyond the scope of most of the wellbeing theories that dare to address climate change mitigation based on human needs. It will also feed policies such as removing the dependence on India for oil products currently dominating transport and industry sectors. In planning, carbon neutrality could possibly be a new variable within Bhutan's GNH policy-screening tool, which is being used by Bhutan for appraising and screening their development policies and projects.

Based on the conclusions from the aforementioned sections 6.1 through 6.4, section 6.5 below reflects on the main research question.

6.5 What will it take for Bhutan to remain carbon neutral, as well as increase its GNH, while its economy grows?

The key to long-term carbon neutrality and increased wellbeing lies with structural changes that can lead Bhutan towards an efficient and low carbon economy, where a sustainable, low carbon energy system is inevitable and can be provided by its hydropower-based electric system. However, the growing difficulty of retaining carbon neutrality will require a careful interplay between economic growth, the GNH strategy and GHG reductions. Carbon neutrality cannot be seen as an isolated national goal, nor can the policymakers and stakeholders be complacent about its long-term status.

The overall results of this thesis show the need for an integrated framework that can bring together the various complementary frameworks that are currently guiding Bhutan on its sustainability journey (see Figure 9, developed as the core of this thesis). Creating carbon neutral economic growth, and increasing wellbeing will also require a sufficiency strategy that complements the technological and resource-oriented decoupling strategy. The three goals of Bhutan can form a solid basis for an integrative policy approach towards operational sustainable development. The core element of carbon neutrality – decoupling and decarbonisation – will essentially enable the net zero emissions that are vital to meet the Paris Agreement. As Bhutan aspires to become a middle-income country, economic growth will be needed that can leverage the financial requirement to deploy low carbon technologies and low carbon infrastructure to sustain Bhutan's carbon neutral pledge. Wellbeing and fairness is promoted through Bhutan's GNH strategy. However, this will require integrating carbon neutrality and economic opportunities that take into consideration GNH, the overarching development philosophy pursued by Bhutan.

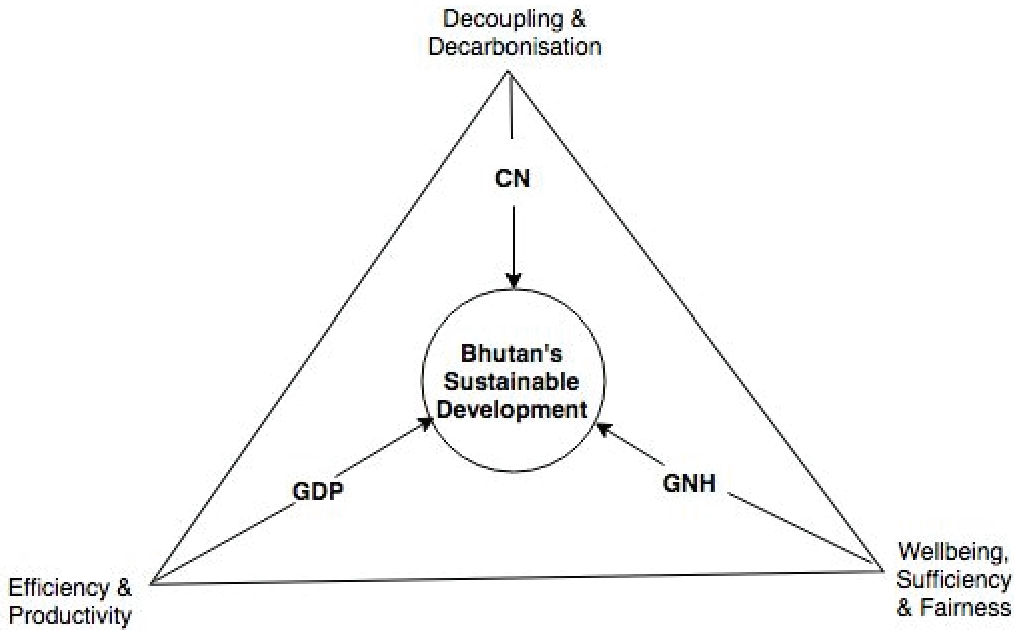

Figure 9. An integrated framework for GNH, GDP and GHG

6.6 Future research

This thesis serves as a foundation for future research. Several areas have been identified that would benefit from further investigation. Although it was not a subject of the research, forest carbon sequestration and accounting remains a contested issue and more research is needed to ensure that Bhutan can continue to use its forest as a legitimate carbon mitigation strategy.

Another area that would benefit from further research is consumption-based emissions assessment and related challenges – notably trade policy and embodied emissions in traded goods. Due to the pace of socio-technical changes occurring around the world, this research recommends that Bhutan conducts frequent reviews and regularly updates its national strategy for carbon neutral development. Literature on rapid decarbonisation recommends updating strategies every two years in the face of disruptive progress.

Considering that Bhutan is committed to maintaining its GNH strategy, future research could investigate the general public's attitudes and views towards the CN pledge and its relation to GNH (which were not included in this research), and what this could mean to their personal lives and livelihoods.

Action research at the product and community level may be required, as none exists to date for Bhutan. This may be more important as Bhutan becomes urbanised, in that urbanisation is mostly associated with rising environmental impacts. However, the idea of urbanisation as an avenue for climate change mitigation and social advancement remains heavily contested. Future research could also apply the integrated framework proposed in this thesis at a micro level, such as at the district and community levels, which can then inform macro level policymaking and implementation. Carbon neutral certification may also be required in the future for Bhutan to access international financing. Similar to CDM projects, national carbon neutral claims could require international accreditation; Costa Rica appears already to be pursuing this requirement.

Finally, considering that the world is constantly searching for nations that can demonstrate sustainability in the era of the Paris Agreement and the UN Sustainable Development Goals, a further area of research could be to document and investigate how the 19 countries that currently comprise the Carbon Neutrality Coalition are achieving carbon neutrality and how they intend to maintain this into the future. Similar to Bhutan, it is likely that they will find the future will need to be grasped through modelling and scenario planning, as well as detailed analysis of the best options that enable their CN to be maintained whilst keeping their social and economic values and goals.

Figure 10. Glaciers and Lake - perennial sources of water for hydropower and human consumption (photo source: Gawa Jamtsho with permission)

Appendix A: Publications

Publication 1- Sustainability in an emerging nation: The Bhutan case study.

Yangka, D., Newman, P., Rauland, V. & Devereux, P. (2018). Sustainability in an emerging nation: The Bhutan case study. *Sustainability, 10*(5), 1622.

This is an exact copy of the peer-reviewed journal paper referred to above.

sustainability

Article

Sustainability in an Emerging Nation: The Bhutan Case Study

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Abstract: With the onset of the 17 Sustainable Development Goals (SDGs) and the Paris Agreement on climate change, the world's nations were to create economic development integrating environmental and social improvement. However, there is still much uncertainty in the world of politics and academia as to whether these integrated goals are achievable and how they can fit best with diverse national and local contexts. Thus, there is always a need to find nations that can show how it can be achieved in different settings shaped by local experiences, challenges, and opportunities. Bhutan could be one of these nations as it could be argued that it has, to an extent, simplified the task to fit its values and aspirations. Bhutan has three major goals that need to be integrated: Wealth (GDP) to align with their middle-income aspiration, thus providing opportunities for employment, Greenhouse Gas emissions (GHG) that are maintained at a carbon neutral level, which is beyond most national commitments, and Bhutan's renowned Gross National Happiness (GNH) index, which covers their socio-economic goals. We show this integration and then synthesize some core findings from a literature review on the theory and practice of sustainable development through the lens of the three integrated goals of Bhutan, thereby placing the case of Bhutan into the wider literature. This paper seeks to show how one emerging nation can model an operational sustainability policy. The paper highlights some plausible synergies between the 17 SDGs and the domains and indicators of GNH that could help nations struggling with how they can create sensible sustainability outcomes from these new global agendas. Bhutan has framed the GNH as its contribution to sustainability. However, this paper suggests that it may be the integration of the GNH with GDP and GHG that is its real contribution. Furthermore, Bhutan's 3G model of fully integrating GNH, GDP, and GHG suggests a way forward for achieving their imperatives of economic growth, whilst enabling the SDGs and achieving the difficult climate change goal. It may also suggest a model for other nations wanting to find a complementary way of framing economic growth, the 17 SDGs, and the Paris Agreement into a coherent set of policies.

Keywords: Bhutan; sustainable development; Gross National Happiness; well-being; carbon neutral; economic growth; emerging nation; integration; holistic; transition; GHG emissions; environment

1. Introduction

In the 1980's, sustainability became a new global concept that emerged from the inadequacies of single-minded economic development [1]. The conclusion from the UN's World Commission for Environment and Development was that economic growth and development was not the problem in itself, but that environmental and social issues had to be improved in the process and not left to trickle down later. The world's nations were then set on a journey to find new ways of integrating environmental and social impacts into economic development. For the past 30 years, many international conferences and agreements have been helping define the nature of sustainable development, from Rio in 1992 to Rio plus 20 [2]. For most of this time, the world has focused on sustainability as the responsibility of the developed world with aid and facilitation of emerging economies to shape their economic development to be more sustainable. This has now changed and the new world of Sustainable Development Goals [3] is making it very clear that the future depends on all nations, including the emerging world, to do economic development sustainably. This paper seeks to show how one emerging nation, Bhutan, is demonstrating how to do sustainable development in their future.

The Sustainable Development Goals (SDGs) have been developed in parallel and integrated into what is perhaps the biggest global environmental issue, climate change. This too began as an agenda for the developed world with the Kyoto Agreement setting out goals for the big polluters and assistance for the emerging world to shape their development more sustainably. However, the Paris Agreement from 2015 is now for every nation to become involved and demonstrate how they can meet the planetary objective of achieving a global economy that keeps emission levels within the 2 $^{\circ}$C rise in global temperature and preferably within 1.5 $^{\circ}$C [4]. This requires Nationally Determined Contributions that can show how every nation can meet their economic goals whilst achieving significant reductions in greenhouse emissions. At the same time, every nation has committed to the SDGs. Thus, there is no room in the agenda for the global future for any nation to say they simply want to create economic development without considering environmental and social improvement. However, there is still much uncertainty in the world of politics and academia that these integrated goals are achievable. Thus, there is always a need to find nations that can show how it can be done. Bhutan could be one of them as it has simplified the case through developing three core goals with each containing measurable indicators. This paper attempts to show how these interconnected goals can enable emerging nations to develop similar approaches to sustainability in the global arena.

Bhutan has three major goals (the three G's) shown in Figure 1 that need to be integrated:

1. Wealth: GDP that can grow to enable them to become a middle-income economy by 2021;
2. Carbon Emissions: GHG that is maintained at a carbon neutral level; and
3. Happiness: Gross National Happiness (GNH) continuing to grow.

Figure 1. The 3G—the three interconnected goals of Bhutan.

These goals represent Bhutan's contribution to demonstrating sustainability. This paper sets out to show this. To the best of the authors' knowledge, no earlier research had attempted to examine the three G's together especially in the context of the 'sustainability puzzle' [5]. The paper thus is also about resolving the conflicts between the three major academic and professional paradigms—economic, environmental and social. The paper seeks to help resolve some of the inherent conflicts between these different areas of thinking and practice.

This paper consists of seven sections with Section 1 providing the background and introduction. Section 2 provides an overview of theories and principles of sustainability and the transition towards sustainability and highlights the confusion being created by disciplinary based approaches to sustainability. Section 3 elaborates on sustainability in Bhutan as viewed through the lens of the three integrated goals and how they relate to the wider literature. Section 4 highlights some grey areas related to Bhutan's socio-economic condition and their development philosophy. Section 5 outlines possible synergies between the 17 SDGs and the domains and indicators of GNH. Section 6 argues carbon neutral development is now a new driver in the global era of Sustainable Development Goals and the Paris Agreement. Finally, the concluding remarks are provided in Section 7.

2. Sustainability Principles, Theories, and Transitions

World history since the Brundtland Commission [1] has been about political processes to resolve the inherent conflicts between economic, environmental and social, the three core dimensions of sustainability. Creating sustainable development is the biggest challenge of the 21st century and several practical and academic attempts have been formalized on how to understand and transition towards more sustainable development.

Principles of sustainability have been developed as a means of establishing frameworks for action on sustainability. For example, Newman and Rowe [6] developed ten principles for the Western Australian State Sustainability Strategy (see Figure 2). Generally national strategies used fewer principles and these have been the basis of much of the international dialogue over the meaning of sustainable development [7] such as the four summarized by Quental, Lourenço & da Silva [8]: the principle of limits, the means and end principle, the needs principle and the complexity principle.

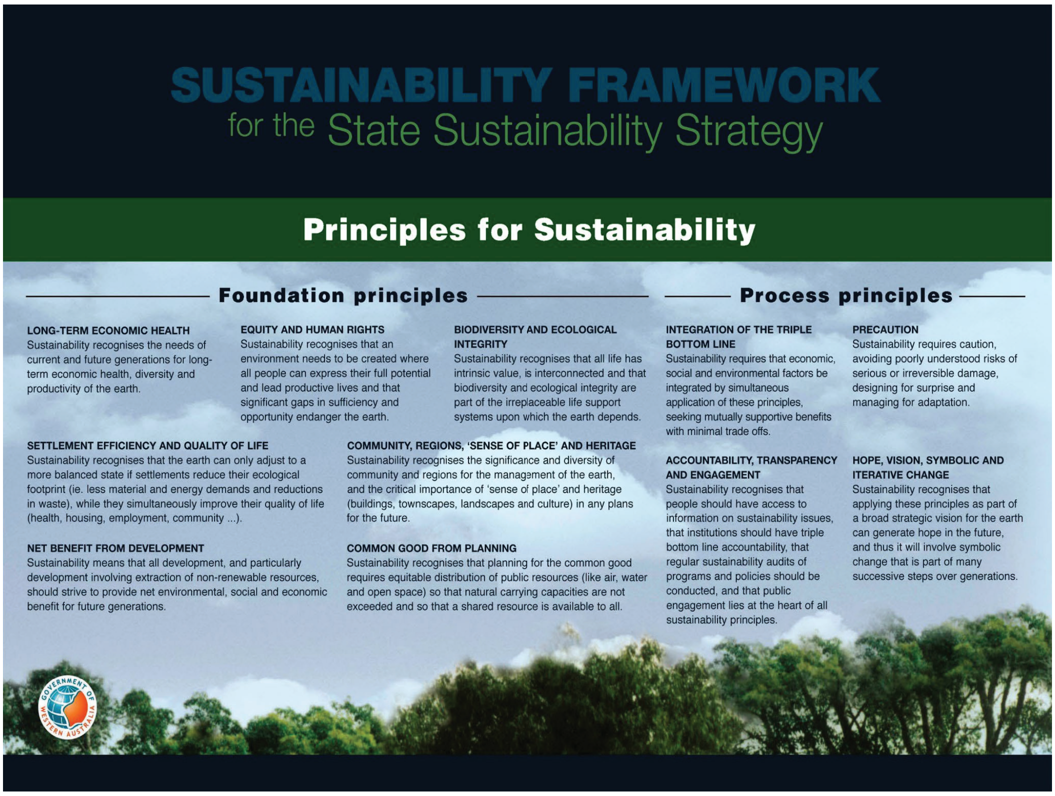

Figure 2. Principles of Sustainability. Source: [6].

Quental, Lourenço & da Silva [8] also conducted a comprehensive synthesis of the sustainability literature to see how the concept was being developed in a more theoretical way. They highlighted three widely accepted scientific approaches to understanding the concept:

1. Ecological economics
2. Sustainability Science and
3. Sustainability Transition.

Ecological Economics emphasizes the limits to natural capital [9,10], while Sustainability Science is about the dynamics and vulnerability of the human and nature relationship [11–13]. Sustainability Transition shows how to transition towards sustainability by asking what to sustain and what to develop [14] and generally uses the work of Geels [15,16] on Socio-Technical Transitions and Socio-Ecological Transitions by Ostrom [17], Cumming [18] and Orach and Shulter [19] including the theory of Panarchy [20]. Markard, Raven, and Truffer [21] suggest the Sustainability Transition is a fundamental transformation towards a more sustainable set of socio-economic activities. They recognize that holistic understanding of sustainable development is hampered by different philosophical and ontological assumptions. For instance, the various forms of sustainability assessments are postulated in the literature, which arose out of focusing on separate thematic areas, leading Hacking and Guthrie [22] to propose a methodological framework to compare those various models.

Conversely, Halog and Manik [23] proposed an integrated sustainability assessment framework by combining the strengths of those various models.

These disciplines are as complex and puzzling as the complexity of integrating the three core elements of Sustainable Development. In this vein, Cumming [18] rhetorically calls it 'disciplinary snobbishness' that forms a major obstacle to delivering sustainable development. This is a big concern as, despite each of these disparate bodies of knowledge using their own ontology to transition towards sustainable development, the global problem may continue. Given such complexity and seemingly confusing theories and approaches to sustainability, Quental, Lourenço & da Silva [8] suggest that sustainability is evolving and that it is an 'integrated thesis' towards consilience of various theories and pragmatic approaches that arose from a multitude of disciplinary backgrounds. But then they caution that it remains to be seen whether this 'integrated thesis' is coherent and useful to finding solutions to sustainability in practice. In this vein, Section 3 discusses Bhutan's 3G model and attempts to explore its possible contribution to the 'integrated thesis'.

3. Bhutan's Sustainability

In 1999, while charting its development course to 2020, Bhutan emphasized that the development pathway must be socially, economically, culturally and environmentally sustainable. It was clearly reflected that 'the principle of sustainability must pervade all our thinking on the future development of the Kingdom' [24]. Earlier research by Brooks [25] vividly described sustainability in Bhutan in the framework of the *Limits to Growth*. The present study outlines sustainability in Bhutan through the lens of its three critical goals. Bhutan equates its GNH concept (see Section 3.3) as the Bhutanese version of sustainable development [26]. This paper attempts to answer if this hypothesis is true and to what extent it helps to see the interaction of the three G's as a more comprehensive approach that includes the other two powerful goals. The other two G's are GDP and GHG. GDP is discussed below and like most nations the goal is to increase economic opportunities through greater GDP growth. In 2009, during the 15th session of the Conference of Parties, Bhutan pledged to the global community that it will remain carbon neutral in perpetuity [27,28]. The pursuit of the GNH philosophy and the hope to remain carbon neutral resonate with the current global sustainable development goals [3] and the climate goal to keep the global temperature rise below 1.5°C, which inevitably requires net zero carbon emissions [29]. To achieve such desirable yet challenging tasks, Newton and Newman [30] reflect that normative goals such as restoring environmental quality, improving human well-being, efficient use of resources, emissions reduction, and others should be addressed through a sustainability transition. How such issues are being addressed in Bhutan under its three interconnected goals are discussed in the following subsections.

3.1. Gross Domestic Product

The economy of Bhutan has undergone significant structural changes over the last decades. In other words, the contribution to GDP by the three major economic activities such as primary, secondary and the tertiary sectors have changed significantly. For instance, the contribution of the primary sector (comprising of agriculture, forestry, and mining) to the stacking of GDP decreased from 56% in 1980 to 27% in 2003 [31] and eventually declined to 16.5% in 2016 [32]. Conversely, the secondary sector which comprises the energy, construction, and manufacturing sectors, increased from 11% to 41%, while that of the tertiary sector remained constant at 33% [31]. These shifts in the structure of the economy show that Bhutan is gradually moving towards a market based modern economy from a traditional agrarian and forestry-based economy.

Over the past decades, Bhutan exhibited an average annual GDP growth rate of 7.6% that led to a steady increase in per capita GDP from US$834 in 2003 to US$2897 in 2016 [32], crossing the threshold for a low income country in 2014 as per the World Bank's criteria, paving the way for a formal graduation to a middle income country by 2021. Paradoxically, Bhutan also went through an economic downturn in 2013 with GDP growth dipping to 2.14%, which fortunately regained to 8% in 2016 [32]. Imports of goods and services accounted for 53% of the GDP clearly showing that Bhutan is an import driven economy. Furthermore, the external debt as a percentage of GDP rose from 62% in 2008 to 101% in 2016 [32].

The growth trajectory in GDP projected by the Asian Development Bank [33] seems to be very positive ranging from 6.6%, 6.8% to 7.4% depending on three alternative scenarios to 2030. This would suggest that the socio-environmentally oriented development philosophy of the GNH outlined below, has not hindered economic development, yet. The imperative of economic growth in an emerging nation like Bhutan means that the nation is always going to enable this to continue so that economic opportunities such as employment and services such as health and education can be provided at a middle economy level. The question is can such integrated development continue as suggested by the GNH? And now there is a new global priority of reducing greenhouse gases so the question also is whether Bhutan can continue its growth into the future as the world attempts radical constraints on greenhouse gases? We discuss the possibilities in Section 6.

3.2. Greenhouse Gas

The increasing concentration of greenhouse gases (GHG) that triggers climate change is mentioned as one of the three global challenges in the 21st century [30]. The 5th Assessment Report (AR5) from the IPCC [34] demonstrated unequivocally that the climate is warming, humans have been contributing to the change, and that this change will bring about a range of impacts on cities, countries, and society. Climate change as a threat to socio-economic development is felt deep inside Bhutan, a tiny nation with net carbon sink and sparsely populated [27], therefore contributing little to climate change. For example, past incidences of glacier lake outburst floods (GLOF) have caused loss of human lives, damage to properties and destruction of cultivated agricultural land and were attributed to climate change [27,35].

In order to limit temperatures to 2 $^{\circ}$C, or preferably 1.5 $^{\circ}$C, significant cuts in carbon emissions are required from all countries [34]. Currently, only nine countries around the world (New Zealand (New Zealand had abandoned its carbon neutral programmes in 2009 [36]), Norway, Costa Rica, Vatican City, Iceland, Maldives, Monaco, Ethiopia and Bhutan) have taken the challenge seriously enough to pledge to become carbon neutral [37]. These nine countries are diverse in geographical size, are at different levels of economic development and are spread around the globe, suggesting that a carbon neutral pathway is possible for any nation state. Encouragingly during the 22nd session of the Conference of Parties (COP 22) at Marrakech, the number of nations that pledged for carbon neutrality had increased to 22. While it is beyond the scope of this paper to compare these countries in terms of their carbon neutral aspirations and/or their implementation plans, it is interesting to note that only one country, Bhutan, has successfully achieved this status [27,35]. Bhutan now faces the particular challenge of maintaining carbon neutrality while it develops its economy from a low base. What will it take for Bhutan to continue carbon neutral development as it graduates to a middle income country?

Carbon neutrality is described in various ways [38,39]. The broadly accepted intention is to balance the carbon in the atmosphere from the inputs and outputs of a product or service, or in Bhutan's case, the whole economy. The process generally requires the measurement, reduction, and finally offsetting of emissions [38]. From a policy viewpoint, Birchall [36] considers carbon neutrality as an extension of long term climate policy and GHG mitigation strategies. At the national level, there is also no universal definition or framework for carbon neutrality, and many of the countries that have pledged carbon neutrality have not clearly defined it, although in some cases broader strategies for achieving it have been outlined.

In this paper, we define Carbon Neutral development in the context of Bhutan as a socio-economic development pathway with net zero carbon emissions at a national level. Similar to earlier definition, this can include the use of carbon sinks (e.g., growing trees) within the geographical boundary of the country, which can be used to offset national emissions. Forest cover, as outlined in the declaration of the Royal Government of Bhutan [27], is at the heart of Bhutan's carbon neutral strategy and the key to Bhutan achieving its carbon neutral status. As early as 1974, Bhutan first instituted a minimum forest cover policy target of 60% (RGoB 2011), and this is now a statutory requirement enshrined in the Constitution of Bhutan. Besides the stringent policy outlined above, the strong forest conservation approach in Bhutan can also be attributed to its low population and difficult accessibility due to its rugged terrain. The latest National Forestry Inventory of Bhutan indicates a forest cover of 71% [40]. The forest cover with a sequestration capacity of 6300-kilotons can be balanced against actual GHG emission of 2200-kilotons in the year 2013 [35]. However, the question will be whether the sink capacity alone keep Bhutan carbon neutral into the future? Will there be a need for a further emission reduction strategy as it grows into a middle-income country? Will it be in conflict with its broader social goals on happiness?

3.3. Gross National Happiness

Gross National Happiness (GNH) was first discussed and adopted by the Fourth King of Bhutan in the 1970s [26,41–43], which is essentially a Buddhist philosophy that "measures the quality of a country in a more holistic way [than GDP] and believes that the beneficial development of human society takes place when material and spiritual development occur side by side to complement and reinforce each other" [44]. In keeping with this, Bhutan has been highly focused on GNH to the extent that its Planning Commission was re-named the GNH Commission [27,45,46]. Even the Constitution of Bhutan now directs the State to enhance the conditions for pursuing GNH [47]. To the Bhutanese, GNH represents their version of Sustainable Development [26]. GNH in Bhutan is being upheld as a living alternative development model [48] as well as a model for achieving Sustainable Development [25]. GNH is widely publicized and well known for its novel approach to well-being policy [49–51]. Acknowledging the interest in GNH by countries around the world, Bhutan initiated a

UN Resolution in July 2011 and subsequently hosted a high level UN meeting in April 2012 for defining a new economic paradigm as part of the SDG deliberations [52]. The new economic paradigm now notes that sustainability is a pre-condition for such a new economic system.

While some call GNH a deliberate strategy to balance the impact of modernization with the values of Buddhist teachings [45], others call it as an invented tradition [43]. Whatever it is called, the underlying aim of GNH is to provide enabling conditions for happiness through its four concrete pillars, nine domains with 33 indicators as shown in Table 1. The 33 indicators further forms 124 variables (see [44]). Alkire [50] considers that the domains of GNH have intrinsic value and are irreducible and non-hierarchical. The 124 variables of GNH are assigned threshold or cut-off values—called 'Sufficiency' (Details on how the sufficiency levels are set are provided in page 22–30 and Appendix 2 and 3 of the 2010 GNH survey report. See Reference [44] Ibid) based on Bhutanese values as well as international and national standards wherever available [44]. How the thresholds are set is based on the socio-cultural and economic conditions of Bhutan. For instance, the threshold for the indicators under the living standard domains are set 50% above Bhutan's national poverty line and the contribution for social support is set at 10% of the annual per capita income [44]. As per the GNH index, a person is said to be happy if he/she achieves the sufficiency level in six of the nine domains [44].

Table 1. Components of Gross National Happiness Index. Source: [44,53].

Gross National Happiness Index		
4 Pillars	**9 Domains**	**33 Indicators**
Preservation of Culture	Psychological Well-being	Life satisfaction Positive emotions Negative emotions Spirituality
	Time Use	Work Sleep
	Community vitality	Donation (time & money) Safety Community relationship Family
	Cultural diversity and resilience	Zorig chusum skills (artistic skills) Cultural participation Speak native language Driglam Namzha (the Way of Harmony)
Conservation of Environment	Ecological diversity and resilience	Responsibility towards environment Ecological issues Wildlife damage

		Urban Issues
Economic Development	Living standards	Per capita income Assets Housing
	Health	Self-reported health Healthy days Disability Mental health
	Education	Knowledge Literacy Schooling Values
Good Governance	Good Governance	Fundamental rights Governance performance Political participation Services

The Centre for Bhutan Studies carried out a national level GNH survey in 2010 and 2015 to ascertain if the nation was increasing in its 'happiness'. The results demonstrated that the national level of the GNH index increased by 1.8% [42]. The main findings of the 2015 GNH survey indicate that people living in urban areas were happier than rural residents as farmers were less happy than other occupational groups. Furthermore, the findings [42] attribute the increase in the GNH index to increases in living standard and access to basic amenities, which is not surprising for a low income emerging nation, suggesting the imperative for economic growth (see Section 3.1). Notwithstanding this, the GNH surveys suggest that diverse groups of people, illiterate or educated, rich or poor, young or old, urban or rural can be happy according to the GNH index, but as noted above, there are differences in happiness levels.

At a national level, Bhutan is considered a "reasonably equitable and sustainable society" [54] with largely happy people despite the low per capita income. For instance, the Gini Coefficient (A commonly used measure of the degree of income inequality [55]) decreased from 0.468 in 2003 [55] to 0.387 in 2012 [56], the population living below the national poverty line decreased from 32% in 2004 to 12% in 2012 [56], life expectancy increased from 47.4 years in 1984 [57] to 68 years in 2013 [58] and the GNH index increased from 0.743 in 2010 to 0.756 in 2015 [42]. In addition, from 1990 to 2015, the percentage of the population using improved drinking water increased from 72% to 100% and access to improved sanitation facilities had increased from 19% to 50% [58]. Brooks [25] and Zurick [59] also observed that the quality of life of Bhutanese had improved over the decades and highlight progress made by Bhutan in development indicators between 1984 and 1998. The Asian Development Bank (2013) attributes Bhutan's socio-economic progress to investments in social infrastructure and services. Can the country's social progress and happiness continue as Bhutan graduates to a middle-income country and beyond? How will Bhutan's carbon neutral pledge impact its social progress as it strides into the future?

4. Some Grey Shades about Bhutan and Its GNH

Notwithstanding this commendable progress, Bhutan's position in some of the indices at a global level were not as remarkable as its own GNH index, which is evident from Table 2. Furthermore, the national debt to GDP ratio steadily increased from 65% in 2008 to 106% in 2016 [32]. More than the low values in these indices, Brooks [25] observed that consumerism has crept into Bhutanese society and is a real test of GNH. SDG 12 (ensure sustainable consumption and production patterns) highlights this as a significant global policy issue that must be addressed. This is relevant for Bhutan in particular, as they will need to ensure sustainable production and consumption levels to maintain their carbon neutral status. Furthermore, the GNH principles advocate balancing the material and non-material components of human well-being. Thus Bhutan, like all countries, is affected by economic development opportunities and external constraints. To this end, Hayden [60] suggested that the sufficiency-based GNH paradigm is facing tough pressure from productivist elements, suggesting the growing issues in implementing GNH-based development, particularly in the profit-centric industry activities. Thus, Bhutan is struggling as a small, low-income nation to balance the need for economic growth, the requirement to keep GHG emissions low whilst increasing gross national happiness.

Table 2. Bhutan's score in some of the globally reported indices in 2016. Source: [61–64].

Sl #	Index	Score	Rank
1	World Happiness index	5.011	97 out of 155 countries
2	Human Development Index	0.607	132 out of 188 countries
3	Press Freedom Index	58	122 out of 199 countries
4	Corruption Perception Index	65	27 out of 176 countries

Given that no single framework can be called a fit-all-type development framework, GNH has its own limitations. For instance, many doubt the replicability of the GNH concepts to other nations and societies [43,59,65]. Giannetti, Agostinho, Almeida and Huisingh [65] consider GNH as an overly ambitious index that is entirely dependent on subjective survey data that are vulnerable to political manipulation. The GNH analysis which relies heavily on survey data was pointed out as a gap in the methodology [66]. GNH is operationalized in Bhutan through periodic surveys and is seen as a policy screening tool but it does not have explicit indicators about energy and climate change so it will always be a disconnect from the SDGs and the Paris Agreement to which they are totally committed. Ura [54] acknowledges that GNH is not measuring ecological wealth, despite incorporating several environmental related variables. Human-wildlife conflicts, which are being experienced by many Bhutanese farmers, are attributed to the conservation policy which arises from the environmental pillar of the GNH [54,67]. All these issues suggest that there are limitations on the supposedly holistic framework of the GNH.

5. GNH and the SDG Mix

Agenda 2030 highlights the need for a holistic development paradigm that embodies health, well-being, ecosystem management, urban sustainability, and governance, which underscores the fact that human development is multidimensional, beyond GDP. This is supported by abundant literature that highlights the shortcomings of GDP as a measure of societal progress [41,65,68–70]. The SDGs are now recognized as a political expression for achieving sustainable development at the global scale and many scientists argue that nexus thinking (A nexus approach is a system-wide approach recognizing inherent interdependencies of different sectors) will provide a governance heuristic to implement and achieve the SDGs [71]. This is suggesting a fundamental restructuring of the prevalent socio-economic system which is underpinned by classical growth-centered economic theory, into a paradigm that is more equitable through pro-poor goals as reflected in SDG 1 (end poverty), SDG 2 (end hunger), SDG 3 (health), SDG 4 (inclusive and equitable education), SDG 6 (sanitation and water management), SDG 7 (access to modern energy), SDG 8 (inclusive and sustainable economic growth) and SDG 10 (reduce inequality).

Since the adoption of the SDGs, nations around the world started assessing the alignment of their existing programs and policies in relation to the SDGs [72]. For Bhutan, a joint assessment by the UNDP and GNHC revealed that 134 out of 169 SDG targets were prioritized in the present 11th five-year plan, which suggests an excellent starting point for Bhutan to implement the SDGs. Wangmo [73] attributes Bhutan's readiness to achieve the SDGs to the prevailing pursuit of their GNH development concept.

The starting point for any principle contains assumptions and values [74]. At the heart of GNH lies the interdependency concept of the Buddhist philosophy—the cause and effect, the so-called the doctrine of 'karma' [49,67] and it is based on the notion of sufficiency [44,54,60]. Thus GNH recognizes interconnectedness, perhaps the essence of sustainability which demands integration of all elements of the development sphere currently being referred to as the triple bottom line, which for Bhutan means the three G's—GNH, GDP, and GHG. Schroeder and Schroeder [75] commends GNH as a model that links happiness to the three dimensions of sustainability. Helne and Hervilami [76] argue for human dependency on the planetary ecosystem and have proposed a 'relational approach' to understand the linkages, which suggests a similar philosophical approach to GNH. Helliwell and Wang [77] argue that a happiness indicator is the most democratic of the well-being measures which provides broader possible ways of making a better world. Giannetti, Agostinho, Almeida and Huisingh [65] suggest GNH to be a powerful communication tool for measuring societal progress towards a paradigm shift away from just GDP. Thus, the underlying values in the GNH have quite considerable support but there are other questions as to whether it can measure meaningfully to provide policy guidance as the SDGs have been created to do.

The nine domains of GNH are interconnected and they are not mutually exclusive [44], which resonates with the indivisibility of the 17 SDGs [3]. The nine domains of GNH and the 17 SDGs illustrates multidimensionality of human development and explicitly contains social, economic and environmental dimensions of sustainability, albeit to a varying degree and specificities (A more thorough comparison would be a useful exercise and provide valuable future research, which remains outside the scope of this paper). The 'sufficiency' concept underpins the threshold settings for components of the GNH (to calculate the GNH index), which informs policy decisions in Bhutan. These threshold values reflect the limits principle of sustainability (see Section 2). Sufficiency in one domain has an inherent tendency to enable other domains according to Alkire [50]. For example, a healthy individual would be expected to have higher life satisfaction. The health domain of GNH integrates well with that represented under SDG 3. Since good governance is critical for the success of any system [78], the 'Governance' domain of GNH intend to address the role of State to provide an enabling environment for growth of societal happiness. Environmental conservation forms one of the four pillars of GNH. Similarly, the SDGs are rich in environmental dimensions from sustainable management of terrestrial and marine ecosystems to clean energy and climate action and even mentions the importance of people living in harmony with nature. Thus, both GNH and the SDGs are framed around integration of multiple dimensions surrounding the role of human beings and societies in the natural world.

While the GNH and the SDGs are similar in their attempts at creating a set of policy-based indicators of human and environmental well-being, both have their own shortcomings and thus criticism. Spirituality is considered a vital indicator for Bhutanese well-being [44] and culture forms one of the four pillars of GNH. 'Time Use' in GNH aspires to avoid 'focusing illusion' [79], whereby people work more hours for material comfort, undermining time available for the intangible aspects of human well-being, which also equally matters. Besides cultural priorities, GNH also emphasizes community vitality, perhaps a building block for a vibrant society. Such vital social connections are inadequately reflected in the SDG except for a parsimonious reference under SDG 11 (ensuring safe and inclusive cities and human settlements). In its present form, GNH does not have enough biophysical indicators to measure the nation's ecological wealth [54], a crucial limit which undermines comprehending the ecological limits for a sustainable habitat for mankind.

GNH recognizes economic growth for alleviating physical poverty, but it also emphasizes the need for spiritual development for alleviating inner poverty manifested by anxiety, insecurity, and other similar human frailties. This is consistent with many commentators who suggest that there are diminishing returns for happiness with increased income beyond a certain threshold level [70,80–82]. On the other hand, the SDGs are driven by mainstream economic theory that suggests only economic growth can alleviate physical and mental ill-being. Another point of departure is that the living standard domain of GNH considers both income base and non-income-based wealth. Furthermore, the 'sufficiency level' used as a cut-off threshold for the 33 indicators and 124 variables of the GNH could be seen as a reflection of the Buddhist concept of contentment, which merits an important place in the contemporary discourse of resource depletion and environmental degradation. This is also reflected in the theology of sufficiency or 'enough' elaborated by some in western traditions though such notions have not been translated into an index like the GNH in the western world. The idea underlying these values is that sufficiency instills more sustainable consumption and production behavior, which is clearly captured under SDG 12. Perhaps the Bhutanese catchphrase 'to know the limit is wise; even too much of mother's milk is poisonous' (Translated into English as understood by the lead author from the original phrase that is in *Dzongkha*, the Bhutanese language) seems to align with assigning sufficiency level in calculating the GNH index.

The recognition of spiritual development, cultural promotion, emotional balance and time balance are perhaps the points of departure of GNH from the SDGs. Verma [48] criticizes SDGs for failing to break away from the prevailing mainstream development approach, which is seen as a point of departure for GNH. Giannetti, Agostinho, Almeida and Huisingh [65] suggests GNH is a paradigm shift away from GDP-only approaches to the future and is a shift of consciousness away from relentless consumerism [49]. But what about the need for clear planetary limits and policy action?

6. Carbon Neutrality Is a Growing Driver

On declaring its intention to remain carbon neutral, Bhutan expressed that "there is no need greater than keeping our planet safe for life to continue" [83], which resonates with the broader vision of Sustainable Development [1]. In a carbon-constrained world, keeping the planet safe invariably demands stabilizing GHG emission levels to hold down temperature rise below 1.5 °C [34]. This requires a global transition towards net zero carbon emissions [29]. The IPCC also recognizes the dual relationship between climate change and sustainable development [84]. To this end, a special volume in the Journal of Cleaner Production emphasized how absolute reductions in material and emissions are essential for a sustainable society [85]. However, such a policy can never be separated from other needs and thus the issues discussed next are how to ensure climate policies can be integrated with GNH and GDP commitments.

Climate change is recognized as a threat to socio-economic development which has a bearing on human well-being but also reducing carbon emissions is sometimes seen as a threat to socio-economic development. Bhutan's goal in their climate change policy is to ensure all three are achieved at the same time. In this way, carbon-neutral development in Bhutan complements the holistic vision of the GNH paradigm, which mixes with the SDGs as demonstrated in Section 5, and at the same time to create GDP to enable the achievement of all the goals together. GDP is thus never seen as a single goal dominating all others but something that can facilitate the achievement of GNH and GHG goals as well as opportunities for jobs and incomes to grow. Reducing GHG is a target area of growth and development to manage global public goods and to keep within planetary boundaries as a strong sustainability strategy [74].

With regard to the plausible relationship between carbon emissions (i.e., central to carbon neutrality) and human well-being, using data from 20 countries fulfilling the criteria of the Goldemberg's Corner [86] domain, Lamb [87] demonstrated that human well-being can be delivered at extremely low levels of energy consumption and carbon emissions; this implies the possible role of a well-being framework in climate change policy as Bhutan has constructed. Bhutan's pledge to remain carbon neutral conforms to the GNH pillar of pursuing environmental conservation, which has remained a key aspect of the development policies of Bhutan. Carbon neutral development requires a reduction in carbon emissions through reduced consumption, as well as through carbon sinks. Low carbon development can be seen as an essential step towards delivering the aims of poverty alleviation, economic growth and enhanced well-being [88], demonstrating strong linkages with the SDGs. Urban [89] argues that low carbon development can be an opportunity for low income countries to pursue pro-poor development and Mulugetta and Urban [88] states that low carbon development is rooted in sustainable development. Kumi, et al. [90] recommend the merit of a pro-poor growth approach to achieving the SDGs. Such concerns can be seen explicitly stated under SDG 1.b which calls for action to: "Create sound policy frameworks at the national, regional and international levels, based on pro-poor and gender-sensitive development strategies, to support accelerated investment in poverty eradication actions" [3]. This is precisely the aspiration of a low-income country like Bhutan to remain carbon neutral while operationalizing the GNH development paradigm. Bhutan's 2011 National Human Development Report [28] recognizes the need to delink carbon emissions from economic and human development. Schroeder and Schroeder [75] therefore hail GNH as a model that attempts to decouple the economy from environmental pressure. Therefore, pursuing carbon neutral development can benefit the GNH vision. Such integration has strong linkages to the SDGs.

Andersson, Nässén, Larsson, and Holmberg [81] showed the possibility of low carbon living without undermining subjective well-being at household level. However, well-being does not appear to increase in a linear fashion along with income, especially when targeting carbon neutrality. Pledging to remain carbon neutral clearly indicates climate change action, which addresses SDG 13. Thus, enhancing human well-being (GNH) and reducing GHG emissions (Carbon Neutral) is possible, while directly linking to the larger goals of sustainable development.

7. Conclusions

Sustainable development has been growing in practice and theory. The three theoretical areas that have developed—Ecological Economics, Sustainability Science, and Sustainability Transitions—have not yet led to a clear link with professional practice and national policy setting. However, they require principles such as inter-generational equity and living within the bio-capacity of the biosphere to modify how economic development is pursued. This paper has attempted to see whether the approach adopted by Bhutan can help provide a better link between the theory and practice, especially in emerging countries where the economic growth imperative is so strong.

Bhutan has suggested that the GNH approach with its clear set of indicators is perhaps a simpler way of understanding sustainability and the 17 SDGs.

GNH-based development aspires to balance material well-being and cultural or spiritual aspects of well-being, which is increasingly being recognized as a necessity for economic development. However, the imperative of economic growth in an emerging economy and the new imperative of rapidly reducing greenhouse gas emissions, are starker drivers in Bhutan and most other countries. Hence, to make sustainable development a truly meaningful and practical set of guidelines for a nation, it is necessary to bring GNH, GDP, and GHG together. Thus, this paper has concluded that 'integrating the three G's' approach to sustainable development may indeed be a better way to approach the future.

Drawing insights from the literature and demonstrating plausible linkages between the GNH and the SDGs, this study has shown that most of the components of the SDGs and the GNH can be linked to some degree, indicating that the GNH paradigm can indeed contribute to achieving the SDGs. However, further examination of the specific goals and indicators under each of the key categories highlighted some gaps and missing links. This presents an opportunity for each of the other two G's, GHG and GDP, to help inform GNH and for the three together to provide direction for how humanity strives towards creating a productive, sustainable and happy society.

Pursuing carbon neutrality complements the GNH development paradigm by specifically targeting carbon emissions, thus addressing climate change, a key element of the SDGs. And bringing the GDP goal into clear focus and then integrating it into the GNH and GHG goals also fills out the idea of sustainable development in a way that is both better in terms of theory and most of all in practice.

This paper has therefore shown that Bhutan, following its GNH development philosophy, along with its carbon neutral declaration, and its GDP commitments, will find the challenge of meeting the SDGs easier than other developing nations with fewer guidelines and targets for holistic socio-economic development. The Bhutan model of fully integrating GNH, GDP and GHG suggests a way forward for Bhutan to achieve the SDGs including the difficult climate change goal, whilst continuing to enable GDP to grow. This combination and integration may also suggest a model for other nations wanting to find a simpler way of framing the 17 SDGs into a coherent set of policies.

We believe that Bhutan provides a showcase for happiness and prosperity within a carbon neutral budget, and thus, a constructive role model for other countries seeking alignment with the new universal sustainable development goals and the Paris Agreement.

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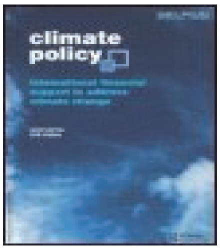

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Carbon neutral policy in action: the case of Bhutan

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ABSTRACT

Climate policy across the world is proceeding at a highly variable pace, with some places very committed to decarbonizing their economies and others just beginning. Emerging nations are generally just starting along this journey. However, among the few nation states that have pledged to achieve carbon neutrality, is Bhutan, a least developed country. Carbon neutrality is an ambitious climate policy that is increasingly being recognized as necessary in order to stabilize global temperature rise at 1.5°C. However, Bhutan is likely to face significant challenges in maintaining this status as the country balances its desire to grow in economic opportunities (GDP) and in human happiness (GNH). Little research has been conducted inside the policy processes to better understand how Bhutan will maintain carbon neutrality. Through open-ended, semi-structured interviews with key stakeholders, this study provides an inside view on the current situation and future challenges that Bhutan may face, along with the complexities associated with implementing and maintaining an ambitious carbon neutral policy. The paper highlights Bhutan's story and how it could be useful for policy learning and knowledge sharing, especially in the context of emerging nations' climate governance.

Key policy insights

- The pro-environmental Constitution of Bhutan and its Gross National Happiness (GNH) strategy provide a unique institutional set up that enables ambitious climate policy innovation.
- Bhutan's forests and hydropower provide resource advantages that support a carbon neutral pledge.
- Bhutan's carbon neutral commitment could be tested and challenged by rural-urban migration.
- Complacency towards future challenges in upholding carbon neutrality is apparent and could prevent the aggressive policy intervention that may be required.
- Varying viewpoints are emerging that could hinder the formulation of appropriate policy measures.

1. Introduction

The international climate change negotiations have prompted countries to begin the process of decarbonizing their economies, but they are yet to result in any significant reduction in global carbon emissions. Even the 2015 Paris Agreement, which has attracted over 175 national pledges to address climate change through Nationally Determined Contributions (NDCs), has been criticized as not being enough to achieve the emissions reduction required to hold global temperature rise to 'well below' 2°C, let alone the ambitious 1.5°C target (Bushell, Buisson, Workman, & Colley, 2017; Höhne et al., 2017). While it is broadly accepted that countries need to transition their economies to a low carbon path in order to meet the challenge of climate change (Mulugetta & Urban, 2010; Nishioka, 2016; Skea & Nishioka, 2008), some argue the transition needs to go beyond this. Rogelj et al. (2015) suggest that global carbon neutrality is needed by mid-century in order to stabilize temperature rise below 1.5°C. The Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5°C specifically focuses on how to achieve the 1.5°C target (IPCC, 2018). Rauland and Newman (2015) also note that pursuing economy wide carbon neutrality will be vital to achieve an 80% reduction in fossil fuel consumption by 2050, in line with the IPCC's (2014) recommendations for temperature stabilization.

However, reducing emissions sufficiently is clearly a challenging task that requires both reduction in energy services demand and switching to renewable energy sources, as well as managing land in a way that enables carbon sinks to grow faster than carbon release. Haszeldine, Flude, Johnson, and Scott (2018) go further, to suggest deployment of negative emission technologies and carbon capture and storage. Geels, Sovacool, Schwanen, and Sorrell (2017b) have shown how the underlying factors contributing to the challenge of deep decarbonization are complex and interconnected within socio-economic systems. Nevertheless, despite the challenges, numerous countries from around the world have made ambitious commitments at the national level to dramatically reduce their carbon emissions. Examples of these commitments are the ambitious pledges originally made by nine countries to achieve carbon neutrality (Flagg, 2015). Bhutan, a least developed country, was among these original nine nations (NEC, 2011). Most of the pledges were made during the 15th Conference of Parties (COP15) in Copenhagen in 2009 (UNFCCC, 2009). While a global agreement was not achieved at this particular COP, these commitments demonstrated the willingness for ambitious action at the national level. Encouragingly, by COP23 in Bonn in 2017, the number of nations that pledged to achieve carbon neutrality expanded to 15 (Carbon Neutrality Coalition, 2017) and, at the time of writing, four more nations had joined the coalition.[1]

Fankhauser (2013) notes the importance for policy makers to cooperate and learn from one another in order to achieve such a deep transformation. Nishioka (2016) argues that in-depth case studies of nations who are able to demonstrate significant reductions have great potential to influence and assist other countries in their transition. Flagg (2018) also highlights the importance and possible role single nation case studies have in helping to better understand contemporary climate change discourse and policy. Given that the nations that have pledged for carbon neutrality are diverse in terms of development stage and country size, these could provide useful lessons for a range of other countries.

Bhutan is a small country but is typical of many emerging countries that want to balance and integrate the multiple development agendas of economic opportunity (measured by GDP), human happiness (measured by Gross National Happiness – GNH) and climate policy (measured by greenhouse gases (GHG)). Bhutan was one of the first countries to declare its intention to become, and remain, carbon neutral in perpetuity. This, then, provides an ideal case study for pursuing how an emerging nation that wants to pursue economic growth and maintain its GNH is likely to manage its carbon neutral status. A number of modelling studies have been conducted on how Bhutan can manage this integrated approach to economic development (Yangka & Newman, 2018) but no research has yet examined the policy process from the inside, that is, from the perspective of those who are pulling the policy levers.

Through interviews with key stakeholders in Bhutan, this paper examines the current and future challenges that Bhutan may face in upholding its ambitious climate policy, how prepared the stakeholders are to address these challenges, and what the opportunities and solutions may be to ensure Bhutan maintains its carbon neutral status into the future. This paper contributes to the climate change policy discourse by highlighting the complexities of pursuing carbon neutral policy, especially in emerging countries seeking to pursue growth objectives. The paper thus gives examples of areas that might need to be addressed by other countries pursuing similar goals, particularly how perspectives from inside the policy process can help manage climate change policy.

2. Background: carbon neutral Bhutan

Bhutan is a small Himalayan nation with less than 800,000 people sandwiched between the world's two most populous nations: India and China. The country is best known to the outside world for its concept of Gross National Happiness (GNH), which is increasingly being acknowledged in the international arena as an alternative development paradigm (Allison, 2012; Brooks, 2013; Schroeder & Schroeder, 2014; Ura, 2015). The essence of GNH is to balance four broad pillars: economic, social, environment and governance.[2] The four pillars comprise nine domains, 33 indicators and 124 variables (Thinley, 2005; Ura, 2015). The origin and overview of the GNH concept is provided elsewhere (Centre for Bhutan Studies, 2012; Givel, 2015; Munro, 2016) and comprehensive details about GNH and its components and how the GNH index is calculated are provided in Centre for Bhutan Studies (2012, 2016). In an effort to embed the GNH principle into policy making and implementation, a GNH policy screening tool was developed and introduced in 2008 by the Centre for Bhutan Studies. The tool is now being used by the GNH Commission of Bhutan (the country's national planning agency), as well as by various national agencies (RGoB, 2015) with an aim to align proposed policies to the GNH strategy.

The country's GNH framework supports the carbon neutral goal; the interplay of these two policy frameworks will be discussed in section 4.1. R. Schroeder and Schroeder (2014) presented GNH as a development model that attempts to decouple economic growth from environmental damage, which is relevant for the contemporary discourse on low emission development (Newman, 2017). Since Bhutan's 2009 pledge was made, a National Low Carbon Strategy was put in place. In addition, maintaining carbon neutrality constitutes one of the sixteen national key result areas under the present Eleventh five-year plan (RGoB, 2013).

Bhutan's net forest cover, which is a cornerstone of the present carbon neutral status, has been maintained at 71% over decades (Ministry of Agriculture and Forestry, 2017).

Currently, the Constitution of Bhutan mandates that the State maintain a minimum forest cover of 60% into the future (RGoB, 2008). In order to meet and maintain the carbon neutral pledge, Bhutan aims to keep its carbon emissions within the sink capacity of its forest cover, which has, until now, been relatively easily achieved. For example, in 2014, Bhutan was responsible for 2.4 million tonnes of CO_2 equivalent emissions (Yangka & Newman, 2018) – a number far below the sink capacity of 6.3 million tonnes (NEC, 2012).

However, considering that fossil fuel consumption from the transport and industry sectors is rising rapidly as seen in Bhutan's energy balance in 2005 and 2014 (Department of Renewable Energy, 2015; DoE, 2007), the question arises around whether the country's carbon neutral status can be sustained at the same level of ease in the future by relying on its forest cover alone. What impact will a changing climate and weather patterns have on hydropower generation, which remains the key source of energy? What role can, or will, the electricity sector play in the future, particularly in helping to decarbonize? These and other challenges will be examined in this paper.

3. Methodology

3.1 Interview design

Semi-structured interviews were used as the primary method for data collection in this study. The interview consisted of 20 questions (see Appendix 2), which were conducted on sixteen participants. Ten of the interviews were conducted in person. The remaining six interviews were conducted electronically through emails.

3.2 Participant selection process

Key stakeholders were identified based on their official position and duties. The selected participants were either executive or senior level officials working in the core agencies in Bhutan, such as energy, forestry, industry and transport, and the environmental commission, as well as international development partners. These key stakeholders were involved in formulating and implementing national plans, climate change policy and governance of energy in Bhutan. Stakeholders that participated in the study were coded as participant 1, 2, 3, etc., and those who did not consent to identify their organizations were coded as Agency 1, 2, 3, etc. It should be noted that participant responses may not necessarily reflect their organization's view. Table 1 lists the participants, their organizations and the mode of response.

A potential limitation of this study could be the lack of feedback from local municipality stakeholders, market actors, national civil society groups or the general public, who were not interviewed as part of the research.

Table 1. List of participants.

Sl#	Name of Participant	Organization	Mode of response
1	Participant 1	Agency 1	Written response
2	Participant 2	Agency 2	Written response
3	Participant 3	Agency 3	Voice recording
4	Participant 4	Agency 4	Voice recording
5	Participant 5	Agency 5	Voice recording

6	Participant 6	Japan International Co-operation Agency (JICA)	Voice recording
7	Participant 7	Gross National Happiness Commission (GNHC)	Voice recording
8	Participant 8	Bhutan Postal Corporation Limited	Written response
9	Participant 9	Bhutan Power Corporation Limited	Written response
10	Participant 10	Road Safety and Transport Authority (RSTA)	Written response
11	Participant 11	Department of Industry, Ministry of Economic Affairs	Voice recording
12	Participant 12	Department of Forestry and Park Services	Written response
13	Participant 13	National Environment Commission (NEC)	Voice recording
14	Participant 14	City Bus Service	Voice recording
15	Participant 15	United Nations Development Programme (UNDP)	Voice recording
16	Participant 16	Department of Renewable Energy	Voice recording

3.3 Design of Questionnaire

The questions were open-ended to provide rich data and were flexible enough to invite and incorporate additional questions and answers. Given the broad-based implications of carbon neutrality, the list of questions may still fail to address some other pertinent issues. Considering that Bhutan has already pledged for carbon neutrality and reaffirmed it in its NDC under the Paris Agreement (UNFCCC, 2017), this study did not examine why Bhutan should be carbon neutral, but rather focused on how carbon neutrality can be maintained. Some questions varied between stakeholders as only relevant questions were asked to the concerned participants based on their official duties and responsibilities.

3.4 Data analysis method

The interview data in this study were analysed with reference to the model proposed by Massey (2011) who categorized data into three levels: articulated, attributional and emergent. Articulated data are the direct responses to the questions raised; attributional data is the information extracted through indirect questions attributed to priori hypothesis or theory; and emergent data are the information that surfaces during the interview without any sort of direct or indirect questions being asked (Massey, 2011). The analysis in the present study is focused mostly on the articulated data and to a lesser degree on the emergent and attributional data. Data were organized and analysed using NVivo Pro (version 11), a computer assisted qualitative data analysis software developed and licensed by QSR International (Leech & Onwuegbuzie, 2011). The nodes were classified to form the themes, which are presented in section 4 with reference to relevant literature.

4.Results and Discussion

Twelve key themes were identified through the analysis, as presented below.

4.1 Policy frameworks: carbon neutrality, Gross national happiness and the sustainable development goals

In general, participants accepted the carbon neutral goal as 'fully-in-sync' with the GNH paradigm, and considered the environmental pillar of GNH as a crucial enabler to leverage carbon neutrality (participants 4, 7, 8, 13, 15). In the same way, carbon neutrality and low carbon development were also seen as essential for upholding the environmental pillar of the GNH paradigm (participants 3, 7, 13). Thus, there appears to be a positive feedback loop between the carbon neutral goal and the GNH paradigm. Similarly, participant 3 argued that human growth has to co-exist with the environment pointing out that from a GNH perspective, the environment is one of the key components to achieve a happy and sustainable country in the long term. Carbon neutrality was also associated with green growth and sustainable development, not just cutting emissions (participants 6, 13). This is in line with Yangka, Newman, Rauland, and Devereux (2018), who propose a 'three G' model – GDP, GNH and GHG's – as a way to develop Bhutan sustainably into the future.

On the relationship between GNH and the UN Sustainable Development Goals (SDGs), participants (7, 13, 15) agreed that they are similar and complement each other, and remarked that Bhutan is in a strong position to pursue them. Bhutan's readiness to address the SDGs has been attributed to its GNH philosophy (Wangmo, 2016), with Bhutan expected to prioritize three SDGs – Climate Change, Poverty Reduction and Life on Land – as accelerators for others (participant 7). Considering possible complementarity, participant 15 stated that, in the era of the SDGs, 'there could be an opportunity to achieve GNH in a progressive, innovative and positive way'.

4.2 Institutional issues

A variety of institutional issues were identified by the participants. These issues were around the existing governance regime, such as the country's laws, regulations and policies, and the organizational set up that steers socio-economic activity, especially those aspects that have a direct impact on the low carbon strategy. Most participants noted that a legislative framework and policies are already in place and there is a strong political will that can sustain carbon neutrality for a long time to come. For instance, the pro-environmental provisions of the Constitution of Bhutan were seen as a platform to enable carbon neutrality (participants 3, 4, 7, 13).

The vehicle quota system in Bhutan (waived import duty for senior government officials) was highlighted as negating the motto behind the vehicle taxation system – i.e. levying heavy tax on fossil fuelled vehicles and no tax for electric cars (participant 13). The need for interventions in the face of the growing industry and transport sectors was also highlighted (participants 6, 10, 11, 13, 14).

4.3 Human resource and climate financing issues

The need for large-scale investment to facilitate a low carbon transition is well understood (Hall, Foxon, & Bolton, 2015; Mulugetta & Urban, 2010), and was pointed out by many participants in this study as a key challenge for Bhutan. In particular, the need to fulfil competing socio-economic development needs was highlighted (participants 7, 13) in light of financing requirements for carbon neutrality. Human resource constraints were identified in the areas of accessing international finance and in using and applying computer aided planning tools (i.e. a lack of staff and/or skills in these two areas), while other respondents either dismissed or did not acknowledge such constraints.

However, participants had different viewpoints on how to garner the financial support required. Participants (2, 6, 8, 10, 15) noted that international development partners (eg Japan International Cooperation Agency) are keen to lend support for a carbon neutral Bhutan. Participants (7, 13) shared the difficulties of securing climate finance, and further mentioned that significant financial contributions will still be required from the Government of Bhutan. To this end, participant 15 suggested that Bhutan should no longer look at development partners as sources of finances, but rather lean on their technical expertise to gain access to other sources. Nonetheless, a few financing windows were highlighted such as BIOFIN, the Biodiversity Finance initiative of the United Nations Development Programme (UNDP) that aims to address financing issues in biodiversity conservation through global partnership (participant 15), the 'Bhutan for Life Initiative', a transition fund mechanism at the national level for supporting conservation efforts in Bhutan (participants 2, 7), Payment for Environmental Services (PES) schemes for maintaining the watershed area for the sustainability of the hydropower sector (participant 4, 12) and ecotourism (participant 7).

Regarding the possibility of an Emissions Trading Scheme (ETS) in Bhutan, participants (7, 15) encouraged exploring it, while another (13) rejected it due to the small potential market in Bhutan. However, the Asian Development Bank (ADB, 2016) considers an ETS as an efficient mitigation measure and recommends Asian countries explore this option. Surprisingly, participants (7, 13) acknowledged that Bhutan has not carried out any cost estimation to sustain the carbon neutral goal, and studies suggest that Bhutan may face challenges due to human resource and financial constraints (Yangka & Newman, 2018).

4.4 Planning tools and the GNH policy screening tool

Understanding the complex interaction between energy, economy and environment demands the use of analytical tools. However, the interviews revealed a lack of modelling expertise and experience (participants 2, 4, 7, 13, 16), as do previous studies of Bhutan, except for a passing remark from a participant on future work on a Computable Generable Equilibrium model to be used by the World Bank to assess Bhutan's NDC. While having access to a planning tool in itself may not enable carbon neutrality, integrated assessment models are widely applied to quantify future challenges and explore plausible solutions through scenario formulation (Nakata, Silva, & Rodionov, 2011; Nishioka, 2016; van Vuuren et al., 2016). Participants (2, 4, 7) reflected on the GNH policy screening tool as being used to align projects and policies towards the GNH strategy by involving a minimum of 15 multi-stakeholders (RGoB, 2015). This could be considered an important area for Bhutan. Considering that only three participants (2, 4, 7) referred to the GNH policy screening tool when discussing planning tools, it appears to support Schroeder's (2015) observation that this policy tool is not used by many of the sub-national actors. However, given that the screening tool is for policy appraisal, not evaluation, it may not necessarily be used by everyone involved at the operational level. In fact, those at the sub-national level use the simple 'GNH checklist' with a view to aligning development activities to the GNH vision (Centre for Bhutan Studies, 2016).

4.5 Topography and urbanization

The country's topography is seen as an enabler to harness hydropower with minimal socio-environmental impact, but as a barrier for rail-based transport systems, which is argued to be crucial for decarbonizing and decongesting road transport (Newman, 2015; Newman & Kenworthy, 2015). While Bhutan's small population can be considered as an advantage in maintaining carbon neutrality long-term, some participants (10, 14) see this factor as a barrier, due to low population density. Despite a small population, rural-urban migration is leading to rapid urbanization in Bhutan, which is expected to reach 77% by 2040 (ADB, 2011). This emerged as a contested issue amongst stakeholders interviewed, though no direct questions were posed on this issue. For example, participant 6 expressed concern over urbanization and rural to urban migration as a threat due to the expected change in people's lifestyles, while others (participants 4, 5, 16) argued that farmland left fallow in the abandoned villages is already turning into forest cover which ultimately increases the carbon sink capacity. It is also obvious that leaving farmland fallow is a direct threat to food security, which was not expressed by the participants. Notwithstanding this, participant 13 expressed the need for smart and localized city designs as Bhutan urbanizes into the future. This highlights how the same issue can be considered either an enabler or a barrier depending on the context. These differing opinions also point towards different sectoral positions and siloed approaches for dealing with policy, highlighting potential challenges to navigating the carbon neutral pathway.

4.6 Transport and industry sector

In Bhutan, the transport and manufacturing industries are emerging as main sources of carbon emissions due to their reliance on fossil fuels (NEC, 2012; Yangka & Newman, 2018). In keeping with this, participants (2, 11, 13) touched on the importance of cleaner production initiatives in the manufacturing industries. One such successful demonstration was carried out in 2004, which was discontinued due to lack of funds (participant 11). This reflects the challenges to financing (see section 4.3). Concerns over the possible negative impact of planned economic zones (industrial development areas in the southern foothills of Bhutan) and mineral development and extraction (participant 2, 11, 13) on Bhutan's emissions level were raised. While participants acknowledged that much will depend on the policy decision to either go for green industries or to continue with highly polluting industry sectors, the economic development policy remains silent on this pertinent issue (RGoB, 2016).

Participants (2, 4, 8, 10, 14) expressed the need to promote electric cars and to advance public bus transportation by improving commuters' accessibility. Participant 8 argued optimistically that it wouldn't be a significant task to phase out fossil fuelled buses and replace these with electric ones considering the small numbers of buses in Bhutan. Conversely, participant 2 cautioned that it is getting late for modal shifting in passenger transport, but that the younger generation may opt for public transport if it is made efficient. With regard to a light rail transport system, some participants (8, 10) shared their optimistic viewpoint, while participant 14 expressed concern over its feasibility given Bhutan's small population. This is yet another issue with divergent viewpoints, indicating potential challenges towards sustaining the ambitious climate goal. The possibility of constructing tunnels through the mountains for a shorter transportation distance to reduce fuel consumption and emissions was also expressed (participant 2).

Beyond this, participant 16 envisioned a hydrogen future for fuelling the transport sector in Bhutan. However, at this juncture, no serious undertakings in this direction can be observed in Bhutan. Moreover, visions for hydrogen-based transport systems seem too far away (Whitmarsh & Wietschel, 2008) and it appears that only endusers perceive it to be a feasible technology, as there are still significant supply side challenges (Kontogianni, Tourkolias, & Papageorgiou, 2013).

4.7 Transitioning economy

Data from the National Statistical Bureau (NSB, 2004, 2017) show that Bhutan is currently transitioning away from a traditional agrarian and forestry based economy towards a more a market based modern economic system, which is likely to result in an increase in carbon emissions. Such socio-economic transitions are a key challenge for Bhutan. For example, the IPAT (Impact = Population*Affluence*Technology) identity (Ehrlich & Holdren, 1971; York, Rosa, & Dietz, 2003) and the Kaya Identity (IPCC, 2000; Kaya, 1990), which are widely used as analytical frameworks for assessing environmental impacts and their drivers, often correlate increasing per capita GDP and population with rising emissions. In Bhutan, per capita GDP increased from US $834 in 2003 (NSB, 2004) to US$2,879 in 2016 (NSB, 2017), and will continue to increase as Bhutan aspires to become a middle-income country by 2023, leading to an increase in emissions, without significant intervention.

Rising consumerism was seen as a threat to maintaining carbon neutrality (participant 2) and, not surprisingly, was also noted as a threat to the GNH principle (Brooks, 2013; Hayden, 2015). Similarly, touching on the problem with taking a myopic approach to development, participant 15 noted that 'development that creates jobs and ultimately destroys the environment will not achieve happiness; it might make people wealthier in the short term, but it certainly won't make the next generation any wealthier and any happier'. However, participants (11, 13, 15) noted that Bhutan's current emissions are far lower than their sink capacity, suggesting that there is adequate 'development space' (Yedla & Garg, 2014) for economic growth as the country aspires to become a middle-income country.

4.8 Role of, and issues with, hydropower

There appears to be much reliance on hydropower, forest cover and a small population for Bhutan to maintain carbon neutrality. Participant 3 proudly acknowledged hydropower as playing a 'singular key role' and having a 'domino effect'. Complementing this, participants (4, 5) argued that the advent of hydropower development had led to forest regeneration through less use of firewood. Participants (13, 15), however, argued that while hydropower helps in reducing emissions from electricity generation, it does not increase the carbon sink capacity, and further cautioned about the risk of relying on a relative mono-economy – that is, an economy affected by a single economic sector – hydropower, in the case of Bhutan.

Notwithstanding the divergent viewpoints, the literature shows that hydropower as a renewable energy source also has its own share of criticism. For instance, some research argues that the decomposition of submerged vegetation from hydropower dams contributes to methane and CO_2 emissions (Li, Wang, Zhou, Cheng, & Wang, 2018; Zarfl, Lumsdon, Berlekamp, Tydecks, & Tockner, 2015). Based on emissions data from 85 hydroelectric dams with global distribution, Barros et al. (2011) identify that emissions are lower in high latitude and temperate regions compared to those in tropical regions. Thus, given that Bhutan is a temperate country located far from the equator and high up in the Himalayas, emissions are likely to be lower than other regions. Bhutanese hydropower developers also carry out compensatory tree plantation in lieu of forest removal during construction. Hydropower in Bhutan also primarily consists of run-of-the-river schemes with no large reservoirs to store water. Nevertheless, it is likely that emissions would still occur from the decomposition of vegetation in the dams, as well as embodied emissions from construction materials (participant 2).

Based on concerns over intermittency, high cost and low plant load factor[3], participants (3, 4, 5) dismissed and discouraged electricity generation from non-hydro renewable energy sources. Others, however, argued that the absence of a feed-in-tariff policy was a barrier to promoting non-hydro renewable energy (participants 1, 2, 9). On the socio-environmental impact of hydropower, participants (4, 5, 16) argued that hydropower dams in Bhutan are located in deep gorges where there are no or fewer human settlements, and that they are nowhere near the size of dams in neighbouring countries. It was also pointed out that service delivery in terms of efficiency and reliability of the electricity transmission and distribution systems could be improved further to encourage end-users to switch towards clean electricity (participants 1, 4, 9). Issues around the impact of climate change on hydropower are discussed further in section 4.11.

4.9 Conflict with ecotourism

Hydropower has also been identified in the literature as being in potential conflict with ecotourism, which is considered as an emerging source of finance for Bhutan (participant 7). For instance, Fletcher (2010) highlights the ongoing debate between dam builders and ecotourism operators, notably white-water kayaking operators in Costa Rica – a country that has also pledged to be carbon neutral by 2021 and which also largely relies on its hydropower for clean electricity. He argues that this debate is a conflict between two different efforts to capitalize on water resources, rather than between capitalism and conservation, but cautions that promoting hydropower as an effective climate change mitigation policy is exacerbating this conflict. While the interview results did not identify these conflicts, there is potential for them to arise in the future, given that both the tourism and hydropower sectors contribute significantly to Bhutan's GDP. At the same time, both these sectors also operate within the policy framework of minimal environmental damage, that is, 'high value, low impact' for tourism and run-of-the-river schemes for hydropower.

The role of Bhutan's GNH screening tool, which to date had been dealing with new policy issues one at a time, could be used to examine a macro-comparison between these two crucial activities and policies. With regard to emissions from international travel (including tourism), these are usually excluded from national GHG inventories

(IPCC, 2006), though Flagg (2018) raised concerns about this issue for Costa Rica. In Bhutan, emissions from jet fuels used in aviation are included under the transport sector (NEC, 2011), though not disaggregated into tourist and non-tourist shares due to data paucity. Interestingly, these issues identified in the literature did not emerge during the interviews.

4.10 Forest cover and carbon accounting issues

Bhutan's Constitution mandates the state to maintain a minimum forest cover of 60% and at present it stands at 71% (Ministry of Agriculture and Forestry, 2017). The concept of 'forest as the baseline' (participants 13, 15), confirms the importance of Bhutan's forests to sustain carbon neutrality. Participant 12 suggested to bring degraded and barren land under tree plantations to increase forest cover, but cautioned on the cost to forest conservation, which is being experienced by villages in the form of human-wildlife conflict.[4] The same participant highlighted the existence of compensatory mechanisms, where trees will need to be planted to compensate for forest land converted to other land uses (i.e. infrastructure development). Participant 6 cautioned against the possible reduction in sequestration capacity due to ageing forests. To address this issue, participant 12 suggested increasing sustainable forest management practices, stating that:

> 'Bhutan could remain carbon neutral provided we are able to manage our forest on the principles of sustainability and other sectors take actions on mitigation [reduction] of greenhouse gases'.

Notwithstanding its crucial role, forest carbon sequestration is also a highly contested issue similar to that for hydropower. For example, the actual amount of carbon sequestration depends on the forest growth rate, soil carbon cycle and temperature of the forest site (van Kooten, 2017), and is impacted by worldviews on the relationship between environment and development (Bääckstrand & Löövbrand, 2006).

In the agriculture sector, farm mechanization was seen as supporting carbon neutrality through land intensification, thereby avoiding conversion of forest land to agricultural land (participant 12).

4.11 Climate change impacts

The impact of climate change is widely recognized as threatening the core economic activities of Bhutan such as forestry, agriculture, tourism and hydropower (Hoy, Katel, Thapa, Dendup, & Matschullat, 2015; NEC, 2011). An apparent paradox is that Bhutan relies on forest cover and hydropower potential for its carbon neutrality status, but these are at risk of climate induced damages. There are studies that highlight glacier retreat and a decrease in precipitation levels in the Himalayas (Li, Xu, Beldring, Tallaksen, & Jain, 2016). Surprisingly, participants (4, 5) do not envisage any near – to medium-term climate induced problems for hydropower. In fact, participants (3, 4) believed that there would be no definitive outcome of climate change impact in the Himalayas, in particular on hydropower. Participants (1, 3, 5, 9, 16) believed that reservoir hydropower could be built to mitigate the impacts of changing hydrology in the event of acute climate change impacts. These issues highlight a need for support to undertake more international research on these issues including how they could impact on Bhutan. Climate change is also expected to cause disruption to ecosystems, and thus potentially increasing human-wildlife conflict in Bhutan (Hoy et al., 2015).

4.12 Other concerns

During the interview process, emergent data arose from some of the participants. For instance, participants (4, 13) raised concern over economic growth and equitable development, pointing out that only a handful of shareholders benefit from dirty and heavily polluting industrial development, and argued that economic development need not necessarily be industrial growth. Creating a sufficient number of jobs quickly in sustainable enterprises and the need for economic diversification, were noted as a key challenge that Bhutan may face in the near future (participant 15). Furthermore, concerns were raised around Bhutan not deriving sufficient national benefits from its efforts to contribute to the global environment (participant 2). In this vein, participant 4 pointed out that:

> 'Sometimes we go off, slightly more ambitious in our commitments to the external world, we offer more and that is the scary part. Let's be happy that we are carbon neutral and have 60% forest cover. We may overdo it. Set [an] example? - I think the world is too large for us. Let's get better off! The fear is trying to say we will do more, I think will be a disservice to the Bhutanese people'.

5.Sustaining carbon neutrality

Sections 4.1 to 4.12 highlighted the issues that shed light on the challenges and plausible solutions to sustain Bhutan's carbon neutrality. These are summarized in the following sections.

5.1 Challenges to sustaining carbon neutrality

The concept of carbon neutrality has been characterized as an idealized emission reduction strategy (Birchall, 2014), suggesting significant challenges to its implementation and ultimate achievement. Fankhauser (2013) identifies the challenges for low carbon growth as the need to have a strong legal basis and a credible roadmap with implementation plans, along with the need to manage wider socio-economic consequences. Low carbon transition is recognized as highly contested and disruptive (Geels, Sovacool, Schwanen, & Sorrell, 2017a) and filled with socio-environmental conflicts (Weber & Cabras, 2017). The interview responses discussed in sections 4.1 to 4.12 touched on many of these challenges, and they are grouped into two broad dimensions: areas where respondents agreed and other areas where their viewpoints diverged (see Table 2). Despite some disagreement among the stakeholders, there was no evidence of potential conflicting views between a participant and his/her agency, although some of them cautioned on this issue prior to the interview process.

Where participants' viewpoints aligned or diverged, Table 2 highlights some of the potential challenges and solutions that could enable or hinder implementation of carbon neutral policy. Any areas of concern raised only by a single participant (for example, issues around ageing trees on carbon sequestration) are not listed in the table. While numerous issues were identified through the interview process on the future challenges of sustaining carbon neutrality, it is also evident that several potential issues identified in the literature were neither raised nor discussed among many of the stakeholders. This neglect could emerge as a potential risk, as highlighted by Fankhauser (2013) around the need for policy competence. It seems that the key challenge would be to strengthen those areas of agreement and address those areas of disagreement. Examples of areas of agreement include that financial support is required and that transport and manufacturing industries are major emitters, while areas still in contention include the need for an emissions trading scheme and whether intervention is even required.

5.2 Solutions to assist with upholding carbon neutrality into the future

As outlined in Table 2, there were several areas where respondents agreed. Much optimism seems to arise from the forest cover and hydropower potential, which underpin Bhutan's carbon neutral pledge. These two factors are perhaps the key internal determinants, which could be labelled as the 'resource advantages' for Bhutan in the context of carbon neutral development – offsetting and avoiding emissions – that support its ambitious climate policy innovation and implementation.

Not surprisingly, the GNH strategy and the pro-environmental provisions of the Constitution of Bhutan support the goal of carbon neutral development. In fact, it appears that the GNH strategy has been effective in instilling environmentally benign policies in Bhutan, in that the environmental pillar of GNH consists of several variables to account for ecological diversity and resilience. In brief, it can be argued that the two strategies taken together form a powerful legislative framework creating a conducive environment to navigate the carbon neutral pathway. These are unique internal determinants which, when complemented by the two resource advantages, make up a formidable combination for Bhutan to pursue and sustain carbon neutrality into the future. The case of Costa Rica is a close comparison (see Flagg (2018) for details).

Despite being hopeful, there is a need for policy intervention to ensure Bhutan's development remains on a low carbon trajectory. Options such as phasing out traditional bioenergy in the building sector, accelerating electric transport and exploring industrial symbiosis were demonstrated through a long term energy economy modelling study (Yangka & Newman, 2018). Similar initiatives have also been highlighted in the literature (Government of India, 2014; Newman, 2015; Shakya & Shrestha, 2011; Shrestha, Ahmed, Suphachalasai, & Lasco, 2013). Beyond the technological solutions, the need to raise awareness about the impacts of GHG emissions among the general public was also suggested. Although afforestation, including bringing more forest cover under sustainable forest management, provides a promising approach for ensuring carbon neutrality, Bhutan should also take stock of the potential unintended consequences of forest conservation and aggressive hydropower development.

Table 2. Areas of agreement and disagreement among participants.

Areas of agreement	Areas of disagreement
The presence of ambitious legislative framework	The impact of the country's topography
GNH strategy is an enabler for carbon neutrality	Whether intervention is required considering existing policies
Hydropower and forest resources as enablers	The role of international financial support
The benefits of a small population	Rural-urban migration and urbanization
The need to have financial support	The need for rail-based transport system
Transport and manufacturing industries as major emitters	The need for an emission trading scheme

In light of the termination of carbon neutral programmes in New Zealand due to changes to leadership (Birchall, 2014), continuity of 'strong political will' seems essential. Research has also found that political stability, rule of law and control of corruption can have a mitigating effect on carbon emissions (Gani, 2012).

Considering that financial constraints emerged as one of the key challenges for Bhutan, exploring the long-term sustainability of the 'Bhutan for Life Initiative', and vigorous analysis of BIOFIN to garner available funding could help to address this. PES activities could be expanded to provide financial support to communities living in and around the catchment area of the riverine system for good health of the hydropower sector.

It is clear that the electricity sector is going to play a much greater role in the future in terms of providing energy to households and for electric transport. If the primary source of electricity continues to be hydropower, this will ensure emissions are kept low and help to maintain carbon neutrality, particularly as demand for these services increase.

6.Conclusion

This study has ventured inside the policy making and implementation process in Bhutan that has been given the task of balancing and integrating the multiple objectives of GDP, GNH and GHG mitigation. The interviews highlight that respondents are acutely aware that Bhutan is providing an example of what other countries will need to strive for in the coming years. However, they are also intent on maintaining growth in GDP and GNH which may impact on their ability to continue with the carbon neutral status. Various challenges were discussed around upholding carbon neutrality in Bhutan in the long term, without more ambitious low carbon interventions. The desire to leave climate policy as it is, without any change, is the easiest way forward in the short term for those dealing with complex trade-offs in development policy. However, in the long term, all participants noted the need to find solutions that could simultaneously improve the economy and happiness of Bhutan, as well as maintain its carbon neutrality.

The core policy options continue to be maintaining forest cover and increasing the amount of clean hydroelectricity, backed up by continuing strong political will and legislative framework. The extra interventions required in industry and transport to decarbonize development are likely to be a test for policy makers as they are not yet able to see how this can be done without impacting on the other goals. If policy makers remain complacent about the potential challenges and opportunities that are likely to be associated with these interventions, this could undermine Bhutan's ability to uphold its ambitious climate policy.

The interviews also revealed some divergent viewpoints among the participants that have the potential to hinder the formulation of appropriate policy measures to meet future challenges. The divergent viewpoints call for effective consultation and collaboration among various stakeholders within different sectoral positions.

Contemporary socio-economic issues such as the need to create employment and equitable income growth also emerged. Some even cautioned that Bhutan's over-commitment to the environment could potentially be a disservice to the Bhutanese people. All this suggests challenges to integrating the three aforementioned core goals.

The findings of this paper could form the basis for future research that could also explore the views of civil society, the general public and private sector stakeholders (not included in this study). This would likely reveal other challenges in Bhutan's carbon neutral journey, particularly around adoption of new behaviours and technologies.

While this study was specific to Bhutan, the likely challenges and plausible solutions identified, as well as the broader socio-economic issues that emerged during the interviews, are likely to be relevant to other countries aspiring to implement ambitious climate policies, while also growing their economies. Examining how Bhutan maintains its carbon neutral path on the ground will provide many lessons to other countries, not only for developing countries who may want to adopt such ambitious goals, but also to the industrialized world.

Notes

1. Climate Home News report: http://www.climatechangenews.com/2018/09/28/19-countries-team-go-carbon-neutral/ (accessed on October 22, 2018)
2. It should be noted that the exact wording/phrase for the four pillars varies in the literature, though not substantively (see Appendix 1 for the lists adopted by various authors). The present study used the four categorical words for simplicity, as they arguably capture the required dimensions.
3. The percentile value of the actual generation to the rated generation capacity of a power plant.
4. Wildlife encroaching onto farmland and destroying crops undermining rural livelihood

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Appendices

Appendix 1. The list of four pillars of GNH provided in the literature

Four pillars of GNH as per (Thinley, 2005):

(1) Sustainable and equitable socio-economic development,
(2) Conservation of environment,
(3) Preservation and promotion of culture and
(4) Promotion of good governance.

Four pillars of GNH as per (Rinzin, 2006):

(1) sustainable and equitable economic development,
(2) conservation of the environment,

(3) preservation and promotion of culture and
(4) good governance.

Four pillars of GNH as per (Pennock & Ura, 2011):

(1) sustainable and equitable social development,
(2) conservation of the environment,
(3) preservation and promotion of culture, and
(4) promotion of good governance.

Four pillars of GNH as per (Centre for Bhutan Studies, 2012):

(1) Sustainable & equitable socio-economic development;
(2) Environmental conservation;
(3) preservation and promotion of culture; and
(4) Good governance.

Four pillars of GNH as per Bhutan's Eleventh Five Year Plan document (RGoB, 2013):

(1) Sustainable and equitable socio-economic development,
(2) preservation and promotion of culture,
(3) conservation and sustainable utilization and management of the environment, and
(4) promotion of good governance.

Four pillars of GNH as per (Brooks, 2013):

(1) sustainable and equitable economic development,
(2) environmental conservation,
(3) preservation and promotion of culture and heritage, and
(4) good governance

Four pillars of GNH as per (Gupta & Agrawal, 2017):

(1) Sustainable and equitable socioeconomic development;
(2) Environmental conservation;
(3) preservation and promotion of culture; and
(4) good governance

Four pillars of GNH as per (Montes & Bhattarai, 2018):

(1) sustainable and equitable socio-economic development,
(2) preservation and promotion of culture,
(3) environmental conservation, and
(4) good governance.

Appendix 2. Interview questions

(1) Considering the underlying need to develop Bhutan's economy, do you think Bhutan can realistically remain carbon neutral 'for all time to come'? How?
(2) What are the main challenges (short- and long-term) you see facing Bhutan in achieving Carbon neutral goal? Is it technological-, financial-, human resource- or institutional barriers?
(3) Do you believe that energy-economy-environmental modelling can provide answers to Bhutan's carbon neutral challenges and opportunities?
(4) How is the current energy system in Bhutan appropriate to achieve carbon neutral development into the future?
(5) What role will hydropower play in the future towards Bhutan's carbon neutral development? What are the opportunities and challenges?
(6) Given the threat of Climate change to the hydropower sector, how can it be more climate resilient?
(7) What role do you see the non-hydro renewable energy sources (such as wind, solar and biomass) playing towards carbon neutral development? What are the barriers and enablers to promoting non-hydro renewable energy sources in Bhutan?
(8) What are the barriers and enablers in the electricity transmission and distribution system to leverage carbon neutral development?
(9) In your opinion, what are the changes required in the Transport and Industry sectors of Bhutan to uphold carbon neutral development?
(10) What is the scope for alternative transport systems in Bhutan? How can Bhutan reduce automobile dependence?
(11) How is the Agriculture and Forestry sector mainstreaming this national goal? What role will the agriculture and forestry sector play for carbon neutral development?
(12) Do you think relying on forest cover alone can uphold Bhutan's carbon neutral goal? What do you think will be the cost of maintaining (or increasing) Bhutan's forest cover?
(13) The forestry sector has a target to increase proportion of forest area under sustainable forest management – what will be the financial implication and the source of funding?
(14) How will the sustainable forest management contribute to Carbon Neutrality compared to the natural forestry system?
(15) What is the current status of PES and what is Bhutan's future plans on PES?
(16) How do you intend to address the issue of changes to forest sequestration capacity due to aging factor?
(17) How should Bhutan minimize the issue of 'environmental burden shifting' raised by some researchers?
(18) What role do you see international climate finances playing in the delivery of carbon neutral development in Bhutan?
(19) What are your views on carbon tax and possibility of emission trading in Bhutan?
(20) How keen is your organization to support Bhutan's carbon neutral vision? How can your organization contribute towards the carbon neutral goal of Bhutan?

Publication 3 - Happiness, environment and wealth: What can Bhutan show us about resolving the nexus?

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Happiness, environment and wealth: What can Bhutan show us about resolving the nexus?

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Abstract

The Environmental Kuznets Curve hypothesis examines how economic development can improve environmental outcomes (called Modernisation theory) or cause worse outcomes (called the Treadmill of Production theory). This paper examines the case of Bhutan, which has committed to implement policies for increased happiness and wealth, while remaining carbon neutral. The difference between the two theories is tested by regression analysis of how economic growth varies with the environmental intensity of wellbeing (EIWB). Regression analysis shows that the case of Bhutan can be explained in terms of the Treadmill of Production theory based on economic and wellbeing growth harming the environment; however, at the moment it is too early in the EKC to come to conclusions. The data also show that population growth helps resolve the nexus in alignment with the Modernisation theory perspective and supports the need to continue urbanisation to resolve these issues. Rather than just simply waiting for economic growth to turn around the EKC, Bhutan should take direct action to maintain its carbon neutral goal and its happiness goal and thus continue to provide a model for the sustainable development discourse in general.

1. Introduction

In the era of the Sustainable Development Goals (SDGs) and the Paris Agreement on Climate Change, the world is struggling to work out how to resolve the nexus between the need for economic growth and enhanced human happiness while living within the environmental limits caused by climate change. Three approaches to these issues were common in the past with commentators from three disciplinary bases: an economist's perspective, where economic growth is always optimised (Ayres, 1998; Nguyen & Nguyen-Van, 2016; Solow, 1956; Stokey, 1998); an environmental scientist's perspective, where environmental outcomes are always optimised (Daily & Ehrlich, 1992; Ehrlich & Holdren, 1971); and a human wellbeing perspective, where human wellbeing is always optimised (Kristjánsson, 2018; Lyubomirsky, Sheldon, & Schkade, 2005; Sachs, 2012; Turner, 2018).

Despite the sustainable development discourse, which tries to integrate all three perspectives, there is a strong reaction in the literature that keeps these three strands separate with little attempt to resolve how they can be integrated. The gap between these approaches seems to be widening; for example, a special volume on 'Absolute reductions' in the *Journal of Cleaner Production* (Akenji, Bengtsson, Bleischwitz, Tukker, & Schandl, 2016) emphasised the need for radical socio-technical transformation that could bring material, energy and emissions within ecological limits. Economic activities were seen to be at the heart of the problem as consumption drives all activities and this is increased by economic growth (Jackson, 2009; Rockström et al., 2009). This is the degrowth movement and is expanded upon to be described as the Treadmill of Production theory.

The alternative approach to economic growth suggests that it can also (eventually) be the driver of changes that lead to decreases in the flow of energy and emissions through technology that becomes more affordable and more politically acceptable as development occurs (Jänicke & Lindemann, 2010; Newman, 2017; Shuai, Chen, Wu, Zhang, & Tan, 2019). The tool used to describe this approach is the Environmental Kuznets Curve (EKC) hypothesis. This tool is widely used to help explain economic–environmental trade-offs. Some studies support it while others disagree with it and for some others there are mixed results (see Section 2). The EKC will be developed further below as the basis of the Modernisation theory. This literature does not include social issues in the triple bottom line nexus, but now there is an emerging research strand that tests the EKC by investigating the nexus between economic growth and the environmental intensity of human wellbeing (EIWB) (Knight & Rosa, 2011; Steinberger & Roberts, 2010) or the carbon intensity of human wellbeing (CIWB) (Jorgenson & Givens, 2015; Sweidan, 2018).

This study follows this emerging research strand by applying it to Bhutan. Using a regression analysis, the paper attempts to examine the case of Bhutan to see if the nexus between these three factors can be resolved and to shed light on how an emerging nation may need to address the overlap behind these issues. Bhutan has pledged to remain carbon neutral while it pursues its famous Gross National Happiness (GNH) strategy for a more holistic development outcome, while growing economically to be a middle-range income country (Thinley, 2005; Yangka, Newman, Rauland, & Devereux, 2018). The case of Bhutan has potential to shed further light on this complex nexus because it takes clear positions on all three areas of happiness (GNH), environment (carbon neutrality) and wealth (GDP).

Bhutan's three goals are quite clearly specified:

1. Happiness, as defined by the Bhutan GNH, is about maintaining a symbiotic relation with nature and balancing material and non-material components of human wellbeing; Bhutan has made a commitment for continuous growth in this area (CBS, 2016; Yangka et al., 2018).
2. Bhutan has pledged to remain carbon neutral in perpetuity; that is, have net zero carbon emissions (Rogelj et al., 2015).
3. Bhutan also desires to be a middle-income country by 2023, while pursuing its GNH strategy.

This suggests that the goals of Bhutan are complex and challenging – requiring the integration of socio-economic and environmental dimensions, which are at the heart of Bhutan's GNH development philosophy and are increasingly associated with sustainable development (Allison, 2012; Brooks, 2013; Frame, 2005). However, until now, no empirical studies have existed for in-depth Bhutan-specific studies on the nexus between economic growth, human wellbeing and environmental pollution, although the possibility of research on linking subjective wellbeing and the ecological footprint has been mentioned (GNHC, 2014). Some studies (Pérez-Suárez & López-

Menéndez, 2015; York, Rosa, & Dietz, 2003a) have included Bhutan in their cross-national level research on issues to do with development and footprint.

Therefore, this paper attempts to fill this gap in relation to Bhutan by using the concept of environmental intensity of human wellbeing (EIWB) (Dietz, Rosa, & York, 2009, 2012; Knight & Rosa, 2011) to understand using data to examine the various conjectures about the nexus between happiness, wealth and the environment. It is hoped that the detailed study of an emerging nation will help the rather conflicted debates that are occurring about these three factors. This will have implications for the contested sustainability discourse, especially in light of the Paris Agreement and the United Nations Sustainable Development Goals (SDG) for other emerging nations.

2. Environment and economic growth theories

In the era of the SDGs and the Paris Agreement, the level of GHG emissions is a key environmental issue, which is perhaps the greatest environmental issue being faced by humanity in the 21st century. However, there are two strongly divergent theories about how to explain the relationship: Modernist theory, which is based on a strongly positive acceptance of GDP-based economic growth as helping to resolve issues of wealth and the environment, and Treadmill of Production theory, which sees GDP-based economic growth as fundamentally causing environmental issues through its link to the IPAT formula.

2.1 Modernisation theory

Modernisation theory (MT) uses mainstream economic development theory to describe how and when environmental factors are brought into the mainstream of development. MT was developed by Joseph Huber (Huber, 2004), and its central tenet is to explore institutional reforms and technological advancement to mitigate ecological crises of modernity (Mol & Spaargaren, 2000; Spaargaren & Mol, 1992). MT uses the EKC as its main tool to explain the evolving relationship between environmental quality and economic development for a country or countries. The EKC tool was first developed by Panayotou (1993). The EKC suggests that an inverted U-shaped curve best explains how economic growth relates to the environment with a certain minimum in growth being required before environmental outcomes start to peak and then decline (Grossman & Krueger, 1995; Panayotou, 1993). The EKC literature has been growing dramatically (Mardani, Streimikiene, Cavallaro, Loganathan, & Khoshnoudi, 2019; Sarkodie & Strezov, 2019), suggesting its importance and the world's growing interest to try and understand the environmental impact of economic development.

Studies to test EKC theory were analysed using regression analysis on time series and cross-sectional data. For example, Song, Zheng, and Tong (2008) used an Ordinary Least Square estimation for a cubic log-log model to assess EKC in the provinces of China between GDP per capita and the three environmental degradation parameters of waste water, solid waste and waste gas, and found that the EKC could explain all three. Similarly, Riti, Song, Shu, and Kamah (2017) also found evidence of EKC for CO_2 emissions and economic growth in China using various regression techniques. Al-mulali, Weng-Wai, Sheau-Ting, and Mohammed (2015) conducted multi-variant regression to examine EKC in 93 countries using an ecological footprint as an environmental variable, and demonstrated that the EKC holds for high-income countries but not for low income countries. Similarly, EKC was found for 10 Middle

East and North African countries (Farhani, Mrizak, Chaibi, & Rault, 2014) and for a group of 132 countries (Chow & Li, 2014). EKC was also confirmed by using an ecological footprint in place of carbon emissions as the environmental impact parameter (Ulucak & Bilgili, 2018).

Other studies have demonstrated six different relationships besides the inverted U-shaped curve between economic growth and environmental pollution (Yang, Sun, Wang, & Li, 2015). Pérez-Suárez and López-Menéndez (2015) examined the EKC puzzle and the forecasting ability of the EKC equation for 175 countries (including Bhutan). They added a third degree polynomial term of GDP per capita to extend the existing EKC equation and found different patterns of EKC, while Bhutan and 10 other countries were classified under 'other cubic pattern' of EKC, a pattern other than the typical U-shaped, inverted U-shaped, N-shaped, or inverted N-shaped curves. The present study will explore whether Bhutan exhibits this pattern when examining the nexus between CIWB and economic growth.

The EKC has been used to support the need for economic growth in emerging nations as the basis not only of poverty reduction, but also environmental improvement, especially if it is connected to urbanisation (Glaeser, 2011). The evidence from Asia is very supportive of this, particularly China, and has been used to generate support for such urbanisation-related economic growth. The Asian Development Bank (ADB, 2012) has shown that Asian countries are significantly earlier in their inverted U-shaped curve and this can be attributed mostly to faster and more dense urbanisation; in recent years, Asia has also had higher levels of renewable energy. Similarly, Jamel and Derbali (2016) have shown that urbanisation in selected Asian countries has a statistically significant negative relation to carbon emissions. Zhang, N., Yu, and Chen (2017) found that the EKC could be established between urbanisation and carbon emissions for 141 countries; this was attributed to urban agglomeration economies that improve the economy and environmental outcomes through economies of scale and density. Similarly, Lin, Wang, Marinova, Zhao, and Hong (2017) argued that economic growth in non-high income countries will decrease carbon emissions and that accelerating urbanisation will lead to only small increases in carbon emissions. Wang, Q., Su, and Li (2018) have shown that urbanisation, income and energy efficiency can allow China and India to pursue economic development without growth in emissions.

2.2 Treadmill of Production theory (TPT)

The TPT was first proposed by Schnaiberg in 1980 (Schnaiberg, 1980), based on a political economy whereby a capitalistic system becomes like a treadmill creating social and environmental impacts without integrating ways to deal with such issues. Thus, TPT calls for fundamental changes to the economic system other than just reform, and GDP is often regarded by most advocates as shorthand for capitalism (Gould, Pellow, & Schnaiberg, 2004). The TPT also now incorporates a more biological approach, developed by a number of scientists and pioneered by Ehrlich and Holdren (1992), who began to try and explain environmental impact using the formula I = PAT. This is a combination of Population, Affluence measured as GDP per capita and Technology measured as impact per unit of GDP. GDP is used in this approach to represent consumption. Quantitative discussions about this approach have been used to show that global impact is likely to continue to increase as long as population and GDP continue to grow (Meadows & Randers, 2012; Rosa & Dietz, 2012). This has been criticised as failing to understand that GDP covers much more than just consumption, failing to distinguish the multiple interactions between PAT, not including social change or political change as factors in environmental impact and not doing justice to spatial factors and agglomeration economies, as in the EKC and the MT approach (Alcott, 2010; Newman, 2011; Waggoner & Ausubel, 2002).

MT suggests that rising economic opportunities will enhance technological advancement and their combination will lead to reduced environmental impact once a certain minimum economic growth level is reached. The TPT, however, suggests that economic growth and technological advancement inevitably accelerates resource consumption – the treadmill – leading to further environmental degradation. The two theories are said to be opposing and orthogonal to each other (Kondoh, 2009).

2.3 Research supporting MT or TPT or both.

Research on the effect of population on carbon emissions found that it was not simply population, but was dependent on household size and age structure (Zhang, Z., Hao, Lu, & Deng, 2018); others have found more than a proportional impact of population on carbon emissions (Dietz & Rosa, 1997; Rosa & Dietz, 2012), although Dietz and Rosa (1997) found that carbon emissions tended to decline at a per capita GDP of US$10,000, which would fit with the EKC approach and thus MT. At a national level, Zhang, L., Mol, and Sonnenfeld (2007) interpreted MT for China and its relevance to the rapid socio-economic growth experienced there in the past decade. At a household level there was modest support for MT, but strong support for TPT was also observed (Adua, York, & Schuelke-Leech, 2016). For Bhutan, it was found that income and education can lead to the choice of cleaner energy (Rahut, Behera, & Ali, 2016), which in turn can reduce emissions. This supports MT, especially from the standpoint of consumer behaviour and technological choices, although the study was not analysed under the MT and TPT perspectives. Renewable energy sources make up cleaner forms of energy and it was found to suit the logics of MT (Curran, 2018).

At the microeconomic level, such as business and firms, the Porter hypothesis (Porter & van der Linde, 1995; Ramanathan, He, Black, Ghobadian, & Gallear, 2017) argues that environmental regulation can trigger technological innovation to reduce impact; an approach that has led to the phenomenon of decoupling. The decoupling agenda and green growth are closely associated with Modernisation theory. Szigeti, Toth, and Szabo (2017) found decoupling between the ecological footprint and GDP in 90% of the 131 countries they examined. Evidence of economic growth decoupling from greenhouse gas emissions was observed globally (Newman, 2017; Schandl et al., 2016). However, Ewing (2017) and Jackson (2009) argue that green growth postulated by MT should be rejected as a way of restoring environmental degradation, as evidenced from climate change and biodiversity loss due to rebound effects.

York et al. (2003a) employed an Ordinary Least Square analysis under the STIRPAT framework (a flexible version of IPAT), and found there was a positive effect of both population and economic growth on environmental degradation – supporting TPT and contradicting expectations of the MT. They also provided data on the eco-efficiency for 142 nations ranging between 2.76 to 0.52, with smaller values being more efficient; for Bhutan it was reported as 0.75. Similarly, Dietz and Rosa (1997) reported the technology multiplier for 111 nations ranging between 0.24 and 5.75, which for Bhutan was 0.47, the smaller value indicating a more environmentally benign socio-economic system. Jorgenson and Clark (2012) also found a positive effect of economic growth and population on total carbon emissions and per capita carbon emissions in their cross-national study of 86 countries. Interestingly, they found relative decoupling between economic growth and total carbon emissions, but observed no relative decoupling between economic growth and per capita carbon emissions, which partly supports both MT and TPT. This suggests that the unit of measurement can affect the analysis and thereby the outcome of the analysis.

The analyses so far have all been related to the nexus between economic growth and environmental outcomes. There is now an emerging research strand that has applied the EKC hypothesis to incorporate variables to capture human wellbeing. These are discussed in the next section.

3. Environment, economic growth and wellbeing

Applying a regression analysis for cross-sectional data for 107 countries, Jorgenson (2014) found that economic development leads to an increase in carbon intensity of human wellbeing (CIWB), and hence greater environmental impact. Similarly, using cross-sectional data for 135 countries, Dietz et al. (2009) showed that increasing environmental impact does not necessarily lead to greater human wellbeing and that the effect of affluence on human wellbeing characterises a diminishing return. Research at provincial level in China found that economic growth has a positive effect, while technological innovation has non-linear and negative effects on CIWB (Feng & Yuan, 2016). This suggests that technological advancement can reduce the environmental stress generated to produce human wellbeing, and is consistent with the expectations of MT. Similarly, using cross-national data on GDP per capita, a subjective wellbeing index and an ecological footprint for 105 countries, Knight and Rosa (2011) supported the TPT but not the MT.

Therefore, in relation to Sections 2 and 3 it can be seen from the existing literature that the debate between the Treadmill of Production theory and Modernisation theory remains unresolved. For that matter, the EKC remains unsettled, while it represents an economic tool for a progressive society. However, there is a clear link between the degree of urbanisation and the rate at which the EKC turns around the inverted U-shaped curve (Jamel & Derbali, 2016; Zhang, N. et al., 2017).

The question in this paper is therefore whether the EKC theories of MT and TPT can explain the empirical relation for Bhutan, which has a clear policy for the three dimensions of sustainability highlighted in Section 1.

4. Method

In line with the existing literature, a multivariate regression technique is used to investigate the relationship between human wellbeing, environmental impact and economic growth, arguably capturing the three dimensions of sustainability. The regression analysis is conducted using EViews, a sophisticated econometrics tool developed with emphasis on time series analysis (Greene, 2001; IHS Global, 2014). This paper used the method deployed by York et al. (2003), which was based on the STIRPAT framework, a stochastic version of the IPAT formulation. Robust least square MM estimation[7] was also used since there were data outliers. The MM estimation was first used by Yohai in 1987 (Yu & Yao, 2017). The MM estimation

[7] MM estimate is a combination of Maximum likelihood (M) estimate and Scale statistic (S) estimate (IHS Global, 2014)

and the Robust Efficient Weighted Least Square (REWLS) were found to outperform other robust estimation methods (Yu & Yao, 2017).

Considering the carbon neutral policy of Bhutan, the present study specifically uses the carbon intensity of human wellbeing (CIWB) in place of the generic EIWB. The CIWB is the ratio between CO_2eq per capita (denoted as CO_2pc), and life expectancy (as LE) was used along with population (as pop) and GDP per capita (as GDPpc), representing economic growth. The details on the choice of these variables are discussed in the next section.

4.1 The choice of variables

The type of variables used for evaluating the environmental intensity of human wellbeing vary depending on the data availability and scope of the study. For example, some studies have used CO_2 emission per capita (Feng & Yuan, 2016; Jorgenson, 2014; Sweidan, 2018), while others have used ecological footprint per capita (Dietz et al., 2009; Knight & Rosa, 2011). Similarly, for human wellbeing, life expectancy is used as a proxy variable in some studies (Dietz et al., 2009, 2012; Sweidan, 2018), while others have used a life satisfaction index (Knight & Rosa, 2011). The choice of variables for the present study was limited by the availability of long-term series data. A longer life expectancy represents healthy living, which arguably indicates physical fitness, health services, good food and all other social embedding that impacts on longevity. While GDP per capita as a measure of economic growth is well known, per capita carbon emissions is of interest for a carbon-constrained world and for carbon neutral Bhutan. In the present study, per capita CO_2eq emissions includes GHG emissions from the energy sector, cement production, and farming and agriculture, thereby capturing most anthropogenic sources of CO_2eq emissions compared to most of the existing research, which has accounted for emissions from energy and cement production only (Jorgenson, 2014; Jorgenson & Clark, 2012; York, Rosa, & Dietz, 2003b). The time series data used in the present study were sourced from the World Bank (2017).

4.2 The regression model

The method based on the STIRPAT framework used in earlier studies (Lamb et al., 2014; York et al., 2003b) was employed to formulate a functional form specified in equation (1). STIRPAT is flexible and it is being used for hypothesis testing and also the elasticity coefficients between the variables can take any value – not restricted to unity as in the IPAT.

$$lnCIWB = C+\beta_1 lnGDPpc+\beta_2(lnGDPpc)^2+\beta_3(lnGDPpc)^3+\beta_4 lnPOP+\beta_5 lnCIWB(-1)+\varepsilon_t \quad (1)$$

Where CIWB is the ratio variable between CO_2pc and LE, adjusted for coefficient of variation to reduce the dominance of one variable driving the ratio (Feng & Yuan, 2016; Jorgenson, 2014). C is the intercept. lnGDPpc is the per capita GDP in natural logarithmic form and the polynomial terms of GDPpc are centred by subtracting the mean of lnGDPpc to reduce collinearity (Knight & Rosa, 2011; Sweidan, 2018; York et al., 2003a). It is also logical to add the lag term of the dependent variable as one of the regressors in a time series data analysis – lnCIWB(–1) for the present study. POP is the population and ε is the error term that captures those unobserved explanatory variables. Finally, β_1 to β_5 are the coefficients of the corresponding explanatory variables that are of primary interest in this study and are to be estimated by regressing equation (1) using EViews.

On regressing equation (1) it was found there was a serial correlation and very high variance inflation factor (VIF). Also the linear term and the quadratic term of the GDPpc were found to be less significant than the cubic term despite being jointly significant, as per the Wald test. This led to constructing two reduced form models: one without the quadratic term (equation 2) and one without the linear term (equation 3).

$$lnCIWB = C+\beta_1 lnGDPpc+\beta_2(lnGDPpc)^3+ \beta_3 lnPOP+ \beta_4 lnCIWB(-1)+\varepsilon_t \quad (2)$$

$$lnCIWB = C+\beta_1(lnGDPpc)^2+\beta_2(lnGDPpc)^3+ \beta_3 lnPOP+ \beta_4 lnCIWB(-1)+\varepsilon_t \quad (3)$$

Small models with fewer parameters were preferred over large models to reduce parameter uncertainty (Agung, 2010). Comparing models 2 and 3, we chose model 3 as it scores relatively better in most of the model selection criteria. It has higher adjusted R^2 and lower Akaike info criterion (AIC), Hannan-Quinn criteria (HC); lower VIFs, and lower SE of regression and standard error for the estimated coefficients. In equation (3), the quadratic- and the cubic-term were jointly significant at 5% significance level as per the Wald test, although the quadratic GDPpc was significant at 25% significance level only. The joint significance is important here, as argued by Brown and McDonough (2016). Moreover, this is within the significance level up to 25%, argued by Agung (2010) for cases where a theoretically important variable becomes statistically insignificant. Furthermore, statistical analysis is considered to be partly a science and partly an art (Gujarati, 2011), requiring trial and error methods. In keeping with this, interpretation of the results in the next section requires caution and is valid within the data set used in this study.

4.3 Statistical tests

For regression analysis, stationarity of data is essential to avoid any spurious regression. In this study, any presence of unit root for all the variables was tested by using the Augmented Dickey Fuller unit root test and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) stationarity test. They were found to be non-stationary at levels, but stationary in first difference. However, if the residual from their regression is stationary that is co-integrated of order I(0), then their combination can be considered stationary (Brown & McDonough, 2016; Gujarati, 2011; Suh, 2013). This condition was fulfilled in this study – that is, the regression results were not spurious.

Statistical tests were conducted on equation (3). The VIFs were below 16 (O'brien, 2007) and it is not reasonable to remove variables just to improve the VIF (Gujarati, 2011). Tests for the presence of serial correlation and heteroskedasticity were conducted using the Breusch-Godfrey (BG) LM test and Breusch-Pagan-Godfrey (BPG) test respectively (IHS Global, 2014; Wooldridge, 2016). The *p*-values failed to reject the null hypothesis of no serial correlation and homoskedasticity. The robustness of equation (3) was also checked through a robust least squares MM estimation confirming the signs of the explanatory variables with small differences for the values of the estimated coefficients and their associated standard errors.

5. Results and discussions

The estimated equation is provided in equation (4) with standard errors in parenthesis. It has an overall goodness of fit (i.e. R^2) of 0.72.

$$\ln CIWB=10.70+0.06*(\log GDPpc)^2+0.374*(\log GDPpc)^3-0.737*\log(pop)+0.505*\ln CIWB(-1) \quad (4)$$

(0.051374) (0.148765) (0.284199) (0.158513)

The estimated equation illustrates that the relation between the CIWB and GDPpc is positive and curvilinear and that with population is negative. The relationship between CIWB and GDPpc is shown in Fig. 1.

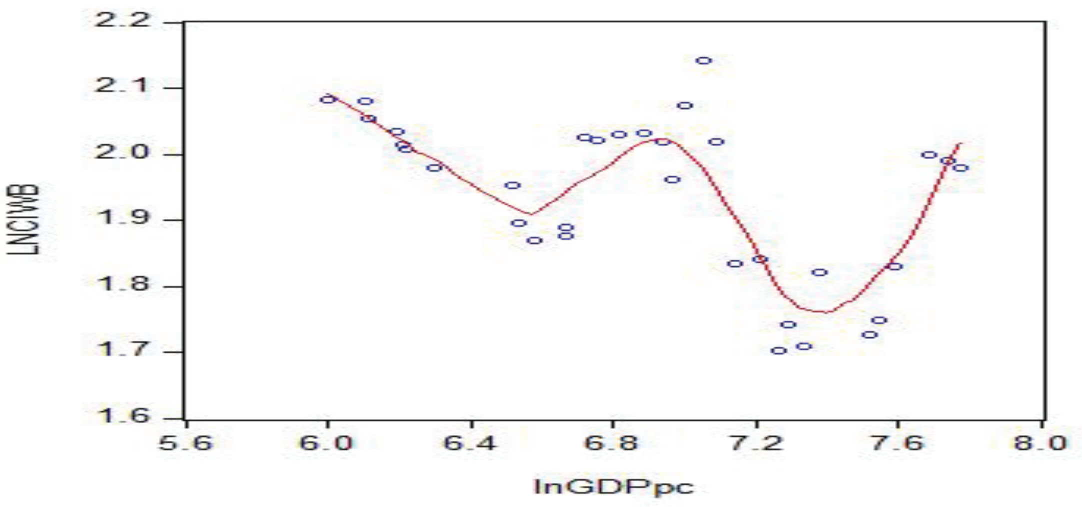

Fig. 1. CIWB plotted against GDP/capita.

The pattern shown by Fig. 1 appears to concur with the 'other cubic pattern' observed in an earlier study (Pérez-Suárez & López-Menéndez, 2015), considering that the cubic GDPpc term in equation (4) is highly significant. Equation (4) suggests that the case of Bhutan supports both the TPT (the GDP result) and the MT (the population result). These findings are elaborated in the following sections.

5.1 Discussing the GDP result

The result of GDPpc causing greater carbon intensity per unit of wellbeing suggests that GDP is not (yet) helping with the social and environmental issues associated with development in Bhutan, as outlined in the TPT. The coefficient of the quadratic GDPpc was comparable with that reported in a cross-national data (York et al., 2003a). Thus GNH, or at least the existing socio-economic pattern, appears to be leading to greater carbon intensity in Bhutan, because enhancing human wellbeing follows a significantly positive and curvilinear relationship with economic growth. Also, economic growth there has not yet reached a level where the EKC curve would suggest it will start to reduce carbon intensity. Thus, at this juncture in Bhutan's growth trajectory, the current per capita GDP is far below the various threshold levels reported in the literature and suggested to occur before the EKC turns around on the inverted U-curve and begins to decline.[8] The way ahead for Bhutan, which is seeking to resolve the three factors of wealth, happiness and the environment, is therefore quite complex.

[8] The average threshold value was found to be United States Dollar (US$) 8910 as per the meta-analysis conducted by Sarkodie and Strezov (2019).

The evidence from Bhutan is that the transition to reduced carbon intensity of wellbeing is not yet under way. In other words, the result supports the Treadmill of Production theory. The result reflects the transitioning of the Bhutanese economy from an agriculture-based economy to a manufacturing and industrial-based economy (NSB, 2004, 2017), the latter being more polluting than the former. To avoid environmental degradation in the early stages of development, Panayotou (1993) suggests that environmental protection should be an integral part of development plans, especially in developing countries. For Bhutan, with its GNH strategy, this has always been the objective. It cannot be stressed enough, especially now with its carbon neutral pledge, that Bhutan will need to bend the emission curve earlier than other nations have managed in the past.

One way to examine whether the EKC is perhaps beginning in a developing country is to examine if the relative decoupling of wealth and environmental impact has begun. Developing countries with low GDP have been found to exhibit relative decoupling (Wu, Zhu, & Zhu, 2018). Bhutan's GDP seems to exhibit a relative decoupling from CO_2eq emissions, as shown in Fig. 2, although this was not the case for carbon intensity of wellbeing. This suggests that there is a need to enhance life expectancy (the denominator of the CIWB), considering that it has changed from 45 years in 1980 to just 68 years in 2012. Moreover, Bhutan is still in its early stages of socio-economic development, thus it is struggling to enhance liveability conditions for its citizenry.

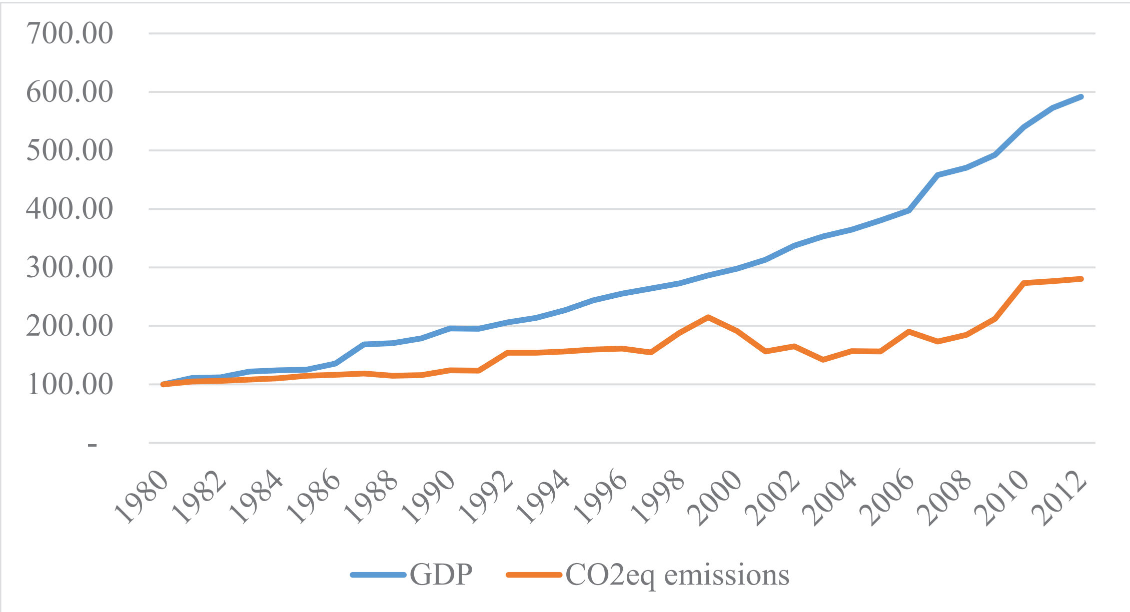

Fig. 2. Economic growth and CO_2eq emissions (based on data source: World Bank (2017).

This calls for a greening of Bhutan's socio-economic activities in line with the aspirations of GNH and carbon neutral status emphasised in their existing five-year plan documents (RGoB, 2013) and their economic development policy (RGoB, 2010, 2016). The need to increase green growth in Bhutan was also emphasised by the World Bank (2014). It can be expected that economic growth in middle-income countries will decrease carbon emissions (Lin et al., 2017), but it needs action sooner rather than later, to be consistent with its global commitments to happiness and carbon neutrality.

5.2 Discussion of the population result

If the TPT approach had been the dominant story for Bhutan, then the coefficient of population being negative in equation (4) would not have been predicted. The result suggests that growing population will help carbon intensity per unit of wellbeing. This finding may seem spurious to the IPAT identity, which considers population to be the main driver of environmental degradation (Dietz & Rosa, 1997; Ehrlich & Holdren, 1971; York et al., 2003a). Furthermore, the finding contradicts the adverse environmental impact of population growth speculated upon in the national strategy of Bhutan (NEC, 1998). One way to explain this in the TPT model is to suggest that consumption (GDP) is overriding the population factor, as Toth and Szigeti (2016) found in their studies. However, it is also possible to see within the MT approach that population growth, if it is in cities, can be an important factor in more rapidly leading to the EKC turnaround that would help Bhutan achieve its multiple goals. Lamb et al. (2014) found this to be the case for population growth in their global study, and for the case of China by Zheng, Yu, Wang, and Deng (2014), and Meng and Huang (2018). The plausibility of this is that in Bhutan farming and agriculture activities, which are concentrated in rural areas, are the major contributors of CO_2eq emissions for the time period prior to 2000 (NEC, 2011). Rural Bhutan accounts for 66% of the total population (NSB & World Bank, 2017).

Therefore, as wealth and population grow, more people will move to the city, which is followed by a series of other factors that may indeed reduce consumption as economies of scale and density create smaller houses, better public transport and other potential impacts on consumption, such as greater recycling (Glazebrook & Newman, 2018; IRP, 2017; Newman, Beatley, & Boyer, 2017; Wang, Q. et al., 2018). Bhutan expects its urbanisation rate to increase from 10% to 51% in just 55 years, compared to 95 years for Asia and 150 years for Europe (ADB, 2012). This trend can be a positive phenomenon as Bhutan aspires to be a knowledge-based society (RGoB, 2016), while also sustaining its carbon neutral goal. Wang, H. (2016) argues that rather than focusing on reducing population, the aim should be to educate and create awareness of how to reduce carbon emissions through behavioural changes. Similarly, Costantini and Monni (2008) emphasise the need to invest in human and social capital to simultaneously achieve a higher living standard and environmental protection.

From Sections 5.1 and 5.2, it is clear that the case of Bhutan provides support for TPT with regard to GDP as the driver and a MT approach for its population growth that is showing positive outcomes, as would be suggested by its rapid urbanisation. Furthermore, urban areas were found to be happier (CBS, 2016) and wealthier (Mehta, 2006; NSB & World Bank, 2017) compared to their rural counterparts. In the interim, as it moves towards the top of the inverted U-shaped curve, there are appropriate policy interventions that can be put in place so that wellbeing and environmental quality are not degraded while the economy grows (Pearson, 1994).

6. Conclusions

Using established econometrics techniques, this study has attempted to interlink the relationships between the carbon intensity of human wellbeing and economic growth as a way of resolving how Bhutan is managing to balance happiness, environment and economic growth. This paper has examined the two main approaches currently being used to explain these interactions: Modernisation theory, based on the Environmental Kuznets Curve, and Treadmill of Production theory, with its basis in the IPAT model. This study has used a 33-year set of data on Bhutan and through vigorous analysis of the time series data on some of the key variables, it has been able to make the following key conclusions.

1. The case of Bhutan appears to support the Treadmill of Production theory as opposed to Modernisation theory, because it indicates GDP is causing carbon intensity per unit of wellbeing to be getting worse. However, this is relatively easy to also explain in terms of Modernisation theory, as it is simply too early in the EKC curve to begin showing the potential reduction in carbon intensity found in more developed places, when examining the nexus between economic growth, human wellbeing and carbon emissions.
2. While the relationship between CIWB and GDP per capita is curvilinear, the relationship between GDP and carbon emissions does not appear to be in lockstep and it seems that relative decoupling is underway. However, there is not yet sufficient economic development for the wellbeing and environmental factors to be more optimised.
3. The case of Bhutan supports Modernisation theory in examining population growth and finding a statistically significant negative relation between population and carbon intensity of human wellbeing. It supports the theory of how the EKC turns around after some economic development, because it is associated with population growth in cities rather than rural areas, and Bhutan is demonstrating all these characteristics.
4. Although Bhutan is still in its early stages of development and aspires to be a middle-income country, it has already pledged to grow in wellbeing and maintain its carbon neutrality. These can only be achieved by decoupling them from the growth in wealth by modifying economic growth to include energy efficiency and decarbonisation policies, as well as continuing the commitment to GNH to enable growth in wellbeing.

This research therefore formally places the case of Bhutan into the burgeoning literature on the Environmental Kuznets Curve proposition, especially as seen through the lens of the ‘environmental intensity of human wellbeing’. It suggests that its current growth trajectory is likely to turn around carbon intensity per unit of wellbeing as it moves more towards being a middle-income country. However, it should not wait to intervene on matters concerning the modification of economic growth in order to ensure its commitments to GNH and carbon neutrality are maintained.

While this study is the first of its kind for Bhutan, it highlights a promising line of research that may further enquire into the socio-technical structure of the Bhutanese economy to complement the quantitative analysis undertaken in this study and provide a more nuanced picture of how it can balance the three goals. Similarly, other emerging nations that are yet to reach the top of the inverted U-shaped EKC may also seek direct ways to deal with social and environmental issues while maintaining their economic growth. Thus by Bhutan maintaining its carbon neutral goal and its happiness goal, along with its economic goal, it is likely to continue to provide a model for the sustainable development discourse in general.

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Conflict of interest

The authors declare no conflict of interest. The funding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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Figure 11. Rapid urbanisation (photo source: Thinley Namgay with permission)

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Article

Bhutan: Can the 1.5 °C Agenda Be Integrated with Growth in Wealth and Happiness?

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Abstract

Bhutan is a tiny kingdom nested in the fragile ecosystem of the eastern Himalayan range, with urbanisation striding at a rapid rate. To the global community, Bhutan is known for its Gross National Happiness (GNH), which in many ways is an expression of the Sustainable Development concept. Bhutan is less known for its policy of being carbon neutral, which has been in place since the 15th session of the Conference of Parties meeting in 2009 and was reiterated in their Nationally Determined Contribution with the Paris Agreement. Bhutan achieves its carbon neutral status through its hydro power and forest cover. Like most emerging countries, Bhutan wants to increase its wealth and become a middle income country by 2020, as well as increase its GNH. This article looks at the planning options to integrate the three core national goals of GNH, economic growth (GDP) and greenhouse gas (GHG). We investigate whether Bhutan can contribute to the 1.5 °C agenda through its 'zero carbon commitment' as well as growing in GDP and improving GNH. Using the Long-range Energy Alternatives Planning model, this article shows that carbon neutral status would be broken by 2037 or 2044 under a high GDP economic outlook, as well as a business as usual scenario. National and urban policy interventions are thus required to maintain carbon neutral status. Key areas of transport and industry are examined under two alternative scenarios and these are feasible to integrate the three goals of GHG, GDP and GNH. Power can be kept carbon neutral relatively easily through modest increases in hydro. The biggest issue is to electrify the transport system and plans are being developed to electrify both freight and passenger transport.

Keywords

Bhutan; carbon neutral; economic growth; electrified transport; emission; energy policy; greenhouse gas; Gross National Happiness; LEAP model; urbanisation; wellbeing

Issue

This article is part of the issue "Urban Planning to Enable a 1.5 °C Scenario", edited by Peter Newman (Curtin University, Australia), Aromar Revi (Indian Institute for

Human Settlements, India) and Amir Bazaz (Indian Institute for Human Settlements, India).

1. **Introduction**

Human society is gradually becoming an urbanised habitat (UN-DESA, 2014) and rapid urbanisation is expected to concentrate energy demand in cities (Newton & Newman, 2013). Urban centres are being recognised as a place for population and economic growth (GDP) (Jiang & O'Neill, 2017). As nations around the world urbanise, reducing greenhouse gas (GHG) emissions will become more critical, which is at the heart of climate policy ever since the establishment of the United Nations Framework Conventions on Climate Change (United Nations, 1992). However, GHG emissions are fully integrated with the economy, hence reducing them is a critical threat to socio-economic development (IPCC, 2014). Recent research argues for net zero emissions between 2045 and 2060 to hold the global temperature rise below 1.5 ºC

(Rogelj, Luderer, et al., 2015; Rogelj, Schaeffer, et al., 2015), and the world's nations have committed to begin that journey in the Paris Agreement by making various pledges. Bhutan has pledged for carbon neutrality, which is a heavy commitment for an emerging nation. The question examined in this article is whether such a plan can be achieved along with Bhutan's other major commitments to growth in wealth and the social goals expressed in the unique Bhutan parameter of happiness, measured as Gross National Happiness (GNH).

A carbon budget for a 1.5 °C consistent world is estimated at 365 Gigatonnes (Rogelj, Schaeffer, et al., 2015). For Bhutan that can be considered as a tiny proportion of just 6.3 million tonnes, but the power of Bhutan's ability to integrate GNH, GDP and GHG emissions can send a strong message to the world. The issue examined in this article is whether such integrated goals are possible for an emerging nation like Bhutan.

GDP is well-known globally, but it is also often criticised for undermining socio-environmental issues. GHG is the primary cause of human induced climate change and is seen in most planning to be inconsistent with GDP, though possibilities of decoupling the two are now appearing (Newman, Beatley, & Boyer, 2017). GNH is a development philosophy for which Bhutan is known to the outside world (Brooks, 2013; RGoB, 2012; Schroeder & Schroeder, 2014; Ura, 2015). The term was first pronounced by the 4th king of Bhutan in the 1970s and it seeks to balance material and non-material development through the integration of its four pillars: sociocultural, economic, environment and good governance (Thinley, 2005; Ura, 2015). Detailed narratives on GNH are provided elsewhere (Alkire, 2015; Centre for Bhutan Studies, 2012, 2016; Thinley, 2005; Ura, 2015) and the importance of GNH to sustainable development and the Sustainable Development Goals (SDG's) is being recognized as well as suggesting potential conflicts with other national goals (Allison, 2012; Brooks, 2013; RGoB, 2012; Schroeder & Schroeder, 2014). How these three goals can be integrated is an important element of Bhutan's planning.

The strong commitment to carbon neutrality is based in the culture of Bhutan. Bhutan is vulnerable to climate change due to low adaptation capacity (Bisht, 2013; NEC, 2011) and being located in the fragile mountainous ecosystem it is highly vulnerable to changes in climate. Thus the bold declaration made by Bhutan during COP15 was to remain carbon neutral for all time to come (NEC, 2011). This was indeed visionary and was reiterated in their Intended Nationally Determined Contribution to the United Nations Framework Convention on Climate Change (UNFCCC) (RGoB, 2015). The need to reduce GHG emissions is being acknowledged by Bhutan (GNHC, 2011; RGoB, 2015) and pursuing a low carbon economy is seen as an inevitable choice to achieve economic development in the face of climate change (Mulugetta & Urban, 2010).

The planning scenarios examined in this article to enable the integration of these three goals inevitably must involve urban planning. Most new development in Bhutan, like all emerging countries, is in cities, especially the capital city of Thimphu. Urbanisation in Bhutan is projected to reach 77% by 2040 with many urban growth centres with implications for more travel demand (Asian Development Bank, 2011). Urban planning will need to play a big part in how Bhutan achieves its goal of remaining carbon neutral while improving its GDP and GNH. Increases in the travel demand will lead to a rise in emissions from the transport sector unless travel demand can be carefully managed and there is a shift to carbon neutral fuels. This anticipated issue is of prime concern given that the petroleum products consumed in Bhutan are 100% imported and the transport sector is thus the major consumer of oil. The rising import of automobiles and fuels and their associated congestion and emissions remain a national concern (GNHC, 2011; NEC, 2011; RGoB, 2012) and will need to be addressed. This concern is not just in Bhutan, it is being felt globally. For instance, the need to cut emissions from the transport sector, which contributed to 23% of global GHG emissions is well acknowledged (IEA, 2016a). How to deal with such critical issues are discussed in many forums including IPCC (2014) and Newman, Beatley and Boyer (2017).

The United Nations Environment Programme 2011 recognises that environmental issues arise as a side effect of socio-economic activity in pursuing a desired goal. To this end, the UNEP (2014) acknowledges that there are more options to achieve significant decoupling if the aim is to increase wellbeing rather than just increasing GDP but of course these are all linked. To this end, the focus of the article is about how climate policy commitments may need to be adapted based on scenarios integrating the three key strategies around GHG, GDP and GNH. The article thus examines how Bhutan could leverage technological options and environmentally benign behaviour to achieve carbon neutral development through scenario-based LEAP modelling (see section 4 of this article).

The following sections provide background on the environmental stance and energy situation in Bhutan, the Bhutan-LEAP modelling, model results and discussions, concluding remarks and policy implications.

2. Environment and Human Wellbeing in Bhutan

A range of environmental issues are examined to show how interconnected they are with human wellbeing.

Bhutan's forest policy mandates minimum forest cover of 60%, which is now enshrined in its Constitution (RGoB, 2008) and encouragingly forest cover is being maintained at 71% (Ministry of Agriculture and Forestry, 2017). Research has suggested this regulation as the key to successful conservation in Bhutan (Jadin, Meyfroidt, & Lambin, 2015), while Buch-Hansen (1997) attributes environmental protection in Bhutan to their enlightened leadership and low population. Brooks (2010) applauds Bhutan as a living lab for integrated conservation and development. To this end environmental protection and wild life issues form some of the ecological indicators of the GNH index, which informs policy making in Bhutan. However forest conservation is encroaching on farm land and rising human-wildlife conflict is being faced by the Bhutanese farmers through loss of farm produce to wildlife where there is no formal compensation mechanism in place (Rinzin, 2006; Ura, 2015). The issue of conservation and rural livelihood remains unresolved (Ura, 2015) and the topical discussion warrants separate research.

Taking GNH seriously, Bhutan conducted a national GNH survey over the two periods[9]—2010 and 2015— the GNH index has increased by 1.8% (Centre for Bhutan Studies, 2016) and its Human Development Index (HDI) also increased from 0.572 in 2010 to 0.607 in 2015 (UNDP, 2016). Over the past decades, Bhutan has witnessed an average GDP growth rate of 7.8% (National Statistics Bureau, 2015). Extreme poverty in Bhutan is said to have been eliminated within the living memory of one generation (World Bank, 2014). While Bhutan is a 36% urban population at present, it is expected to reach 77% by 2040 through urban expansion and also due to rural to urban migration (Asian Development Bank, 2011). For instance, the population of Thimphu—the largest urban centre in Bhutan—is expected to increase from 147,000 in 2015 to 300,000 in 2040 (Asian Development Bank, 2011). The Asian Development Bank attributes the rural to urban migration as a consequence of aspirations for a better lifestyle ensuing from better amenities in urban areas, which are called an 'urbanisation bonus' (Lin & Zhu, 2017). However rapid urbanisation along with industrialization were seen as the drivers of GHG emissions in South Asian countries including Bhutan (Shrestha, Ahmed, Suphachalasai, & Lasco, 2013). Furthermore, being in the fragile ecosystem of the Himalayan range, Bhutan is very much vulnerable to the impacts of global climate change (GNHC, 2011; Hoy, Katel, Thapa, Dendup, & Matschullat, 2015; NEC, 2011). Bisht (2013) even suggests that climate change is the key determinant of Bhutan's future development and security. Climate change policy entails reducing GHG emissions. Plans for reducing GHG emissions centres around the energy mix and energy use, lifestyle, economic activities and land use forming the main drivers of anthropogenic GHG emissions (IPCC, 2014). Considering the energy system as one of the key drivers of GHG

[9] There was a GNH index for 2008, however the survey conducted in 2007 for that index has been noted as a preliminary survey with fewer questions and covering fewer districts to collect feedback and further expand the questionnaires that were then used for the next two nationwide GNH survey (Centre for Bhutan Studies, 2012).

emissions, a brief background of the current energy system of Bhutan is provided.

The energy mix in Bhutan comprises: Hydropower (28%), biomass (36%) and fossil fuels (37%). At 42.86 kW/capita, Bhutan has the highest theoretical hydropower potential in South Asia (Shrestha et al., 2013). However, the per capita energy consumption at 36 GJ (Department of Renewable Energy, 2015b) is 55% lower than that of the world average at 79 GJ (IEA, 2016b) suggesting there is potential to increase the hydropower side of the economy. The sectoral energy shares are shown in Figure 1 (Department of Renewable Energy, 2015b). Fossil fuels are predominantly used in transport and industry and their associated emissions could undermine any potential future carbon neutral pathway especially in the near future as the economy of Bhutan expands. The need to reduce GHG emissions is being acknowledged by Bhutan (GNHC, 2011; RGoB, 2015) and to this end a National Low Carbon Strategy has been developed (NEC, 2012). However, the strategy document assumes demand saturation in the industry and transport sectors after 2020, thereby underestimating the challenges of the rising energy and emissions from these two sectors, the main contributors of GHG emissions in Bhutan. To this end the following section intends to highlight the challenges and opportunities to reduce GHG emissions in the two sectors-policy directions will be concluded after the scenario analysis.

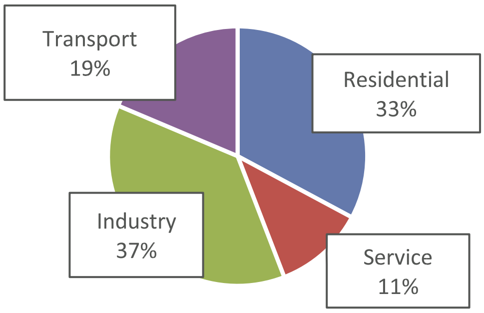

Figure 1. Sectoral energy share (%). Calculated based on Department of Renewable Energy (2015b).

3. Challenges in the Transport and Industry Sectors

Between 2005 and 2014, energy demand in the transport and industry sectors grew at a compound annual growth rate of 9% and 11% respectively, whereas that of service and residential sectors grew at 4% and 1% respectively (Department of Renewable Energy, 2015b; DoE, 2007).[10] At this growth rate, the transport and the industry sectors being major consumers of oil and coal have the potential to derail the carbon neutral pathway of Bhutan. This is the kind of issue faced by many emerging nations.

Furthermore, the transport and the industry sectors are considered to be hard to decarbonize (Rogelj, Luderer, et al., 2015) nonetheless it is not impossible. Industry can be electrified but transport will require a more complex set of urban planning policies.

Urban planning has developed an approach to promote pedestrianisation and bus based public transport in the urban areas of Bhutan (Asian Development Bank, 2011) and plans have been developed to electrify both freight and passenger transport in Bhutan (Hargroves, Gaudremeau, & and Tardif, 2017). A study on transport electrification in Nepal (Shakya &

[10] Authors' calculation based on the referenced sources.

Shrestha, 2011), a neighbouring country to Bhutan with similar topography, found there were economic benefits, employment generation, enhanced energy security as well as beneficial environmental outcomes in such a policy. For carbon neutral transport, recent research (Shafiei, Davidsdottir, Leaver, Stefansson, & Asgeirsson, 2017) has highlighted the need for radical changes both at the supply side and the demand side. Empirical studies at the global level have advocated rail based transport to reduce automobile dependence and associated emissions (Newman & Kenworthy, 2015; Newman, Kenworthy, & Glazebrook, 2013). Kołoś and Taczanowski (2016) found light rail to be feasible in medium sized towns in central Europe with a population between 100,000 to 300,000 and there are many cities with population just over 100,000 having such rail systems as a successful mode of transportation (Newman et al., 2013). The above approaches to urban planning will be included in the modelling outlined below.

With this as background the article will now show how the complex integration of GHG, GDP and GNH has been attempted as the basis of generating policy scenarios.

4. Methodology

This study expands on the Bhutan-LEAP model developed by Yangka, Newman and Rauland (2017) but with distinct scenario characterisation not covered in the previous work. LEAP stands for the Long-range Energy Alternative Planning system model, which is a flexible and user-friendly energy-environmental planning tool developed and licensed by the Stockholm Environment Institute (Heaps, 2016). However, LEAP is not a climate simulation model having earth system dynamics, though it is being used to assess climate policy through scenario based energy system analyses and associated GHG emissions. For instance it is widely used for climate policy assessment and low emission development notably in developing countries (Kumar & Madlener, 2016; Ouedraogo, 2017; Sadri, Ardehali, & Amirnekooei, 2014; Shakya, 2016). The scope of an energy model is inherently vast (Nakata, Silva, & Rodionov, 2011), it is limited by the research questions that are being evaluated and the scenarios that are being formulated to address those queries. Once a database is developed, any pertinent issue can be studied within the scope and limitations of the model. This study used a scenario-based long term energy-economy modelling, which is acknowledged as an important method to explore uncertainties in the future (O’Neill et al., 2017). The alternative scenarios were formulated to address the present research objective.

4.1. Structure of Bhutan-LEAP Model

Bhutan-LEAP model was structured into key assumptions, demand branch, resource branch and non-energy branch. The planning horizon extends from 2014 to 2050. The demand branch is comprised of transport, industry, residential and service sectors to account for energy consumption and associated GHG emissions, and to study plausible policy interventions to contain the rising emission levels. Further disaggregation to sub-sector levels were limited by data availability. For instance, the tourism sector[11]

[11] The brief note on tourism sector was provided to address the comment of a reviewer on the tourist sector being neglected in this article.

wasn't shown as a separate sector in the model due to lack of data on energy consumption specific to the tourism sector. However, the service sector shown in the model includes the commercial sector (such as hotels and restaurants) which are impacted by the number of tourists (NSB, 2017), suggesting that the energy consumption under the service sector can be assumed to include energy consumption by the tourists visiting Bhutan. Furthermore, energy consumption in air transport can also be assumed to be impacted by the tourists coming to Bhutan given that 2/3rd of the flight passengers are tourists (Asian Development Bank, 2011).

4.2. General Assumptions

In this study a discount rate of 10% was used, consistent with that used in earlier studies and furthermore, a discount rate of 10% is mentioned as a global average opportunity cost of capital in a study on low carbon development for India conducted by World Bank (Gaba, Cormier, & Rogers, 2011). Considering forest cover of Bhutan as a carbon sink, for accounting purposes the emissions from wood-based energy consumption were accounted as positive rather than as a carbon neutral energy source. The emission factors for the demand technologies and the fuels were referred from the Technology and Emission Database of the LEAP model provided by SEI (Heaps, 2016). The emissions from waste disposal and agricultural activities—farming and livestock rearing—were accounted for under 'non-energy'. The amount of waste generation and disposal were assumed to increase along with urbanisation, whereas emissions from agriculture were assumed to remain constant as per the past trend (NEC, 2011). This assumption is plausible due to the ongoing rural to urban migration that is causing decline in the farming activities and livestock rearing. Furthermore, the amount of agricultural land in Bhutan is limited due to topography and forest conservation.

Paucity of data on long-term macroeconomic parameters, cost and technological datasets for various demand technologies poses a daunting task, hence surrogate data from the literature were imputed and adapted, with consequent implications for the model results. In this regard, higher confidence levels could be placed on the data that were sourced from Bhutan specific studies.

4.3. Distinct Features of Bhutan's Energy System

From a modelling perspective, the energy system in Bhutan is relatively simple in that the energy supply side does not have the complex fossil fuel extraction and conversion processes except for limited coal mining and the hydropower system. Similarly, there is no rail system or transport using water ways and limited domestic air ways. Furthermore, accounting for primary energy supply and final energy consumption are similar except for the transformational losses occurring in the electricity system (Yangka & Diesendorf, 2016). Bhutan neither has oil reserves nor oil refineries, thus petroleum products consumed in the demand sectors are 100% imported.

4.4. Projection of Energy Demand and Energy Prices

Future prices for petroleum products, which are 100% imported from India were assumed to follow the international oil price and thus indexed to the price changes calculated from future oil price projection done by the US-Department of Energy (US Energy Information Administration, 2016). Oil import dependency of India itself is expected to increase from 74% in 2013 to 91% by 2040 (IEA, 2015). Bamboo chips and wood charcoal which are mostly imported from India for use in the Industry sector were assumed to rise at 4.1% per annum (Feuerbacher, Siebold, Chhetri, Lippert, & Sander, 2016). The projected energy prices and end-use energy services in the four sectors are provided in the Annex.

The end-use energy services such as the heating, cooking, passenger travel, freight travel, which drives the corresponding energy demand are projected through the expression builder[12] under the activity variable of the demand module of the LEAP model.

5. Scenario Storyline

This article formulated two base scenarios and two corresponding alternative scenarios. The two base scenarios are: the Business as Usual (BAU) trajectory and a trajectory based on high GDP (HGDP). Their characterisation and key features are provided in Table 1. The two alternative scenarios intend to investigate the future that Bhutan aspires to—societal happiness within net zero greenhouse emissions reflecting carbon neutral development in a GNH state. These alternative scenarios attempt to contain the rising emissions from the BAU and the HGDP scenarios within the carbon sink capacity available for Bhutan. The storyline acknowledges that human settlements are sooner or later expected to be largely urbanised (Jiang & O'Neill, 2017; Newton & Newman, 2015).

The alternative scenarios are designated as Knowledge-Based Society (KBS) and GNH society, which are outlined in sub-sections 5.1 and 5.2 of this article. The GNH scenario is inherited[5] from the BAU scenario, while the KBS scenario is inherited from the HGDP scenario. Under these two alternative scenarios, a case study, with and without light rail transport, was also conducted to examine how light rail can support the carbon neutral pathway of Bhutan.

5.1. Wealthier and Knowledge Based Society (KBS)

This scenario imagines human settlements in Bhutan moving towards a greater proportion knowledge based economic activity in urban society during the later part of the planning horizon and enjoying a high economic outlook as a result of this. The Bhutanese society is likely to embrace such knowledge economy goals which include walking and public transport based on light rail and aggressive expansion of electric vehicles (Newman & Kenworthy, 2015). Such economic activity is less intensive in both energy and emissions. Being a KBS, the contribution of the service sector to the national GDP increases while that from the Industry sector decreases. The specificities of this scenario were outlined under Table 1.

5.2. GNH Based Society

This scenario contemplates a happy society derived from community vibrancy and symbiotic relationships between the human and the natural world, manifesting the essence of GNH—balancing material and spiritual development and co-existing with nature. The economic pathway under

[12] A flexible feature in LEAP, which allows user to write mathematical expressions to link various branches (the component of the LEAP structure). [5] 'Inherited' in LEAP model can be simply understood as 'derived from' or 'built on'.

this scenario is assumed to follow the GDP growth rate of the BAU scenario (7.8% growth rate in the medium term and sustaining at 5.6% growth rate by 2050). Community vibrancy is defined as the people adopting the walking and public transport system. Harmony with nature is defined as less polluting and with more efficient socioeconomic activities including more knowledge-based activity. These definitions are for modelling purpose only. Similar to the KBS scenario, the specificities of this scenario were outlined under Table 1. While this is an initial attempt to construct scenarios around some key features of the GNH, there is no way to incorporate the entirety of GNH into the modelling work. We expect future work to expand on this.

6. Results and Discussion

The model results for the BAU scenario and the alternative scenarios are presented and synthesised with relevance to the 1.5 °C climate consistent world. The results discussed in the following section do pose a certain level of uncertainty attributable to the assumptions of the key variables, use of data which were adopted from various

Table 1. Key features of the four scenarios.

Scenario	Residential sector	Service sector	Transport sector	Industry sector
BAU (GDP growth rate of 5.6% and increasing to 7.8% and sustaining at 5.6% until 2050)	Energy demand increases with the increase in the number of household; Fuelwood usage in all end-uses expected to decline to 23% by 2050 following the declining rural population; Saturation level of households with heating facility increases from 50% in 2014 (NSB & ADB, 2013) to 70% by 2050.	Energy demand increases with value added of the service sector; Fuelwood usage expected to decline.	Energy demand in passenger transport increases with per capita GDP and that for freight increases with the value added of the transport sector; Share of passenger travel demand met by bus increases from 15% to 25% by 2050; Share of passenger travel demand met by air transport increases from 20 to 25% by 2050; Share of freight travel demand met by light diesel truck increases from	Energy demand increases with value added of the industry sector.

			17% to 30% by 2050.	
GNH state (GDP growth rate assumed to be sufficed with the BAU growth rate)	Firewood and kerosene used in the building sectors reaches zero by 2030 and substituted by electricity and biogas.	The GDP share of the Service sector increases from 33% to 45%.	Walking meets 10% and light rail meets 30% of the passenger travel demand by 2050. Electric vehicles were assumed to penetrate at half the rate specified in IEA (2016a).	The GDP share of the Industry sector decreases from 11.70% in 2014 to 10.70% by 2050; A move towards industrial symbiosis.
HGDP	High economic outlook of 10% in the medium term and declining to 5.6% by 2050.			
KBS—Knowledge based society with high economic outlook	Dirty fuels used in the building sectors reaches zero and substituted by electricity and biogas.	The GDP share of service sector increases from 33% to 45%.	Walking and light rail meets 10% and 30% of the passenger travel demand respectively by 2050; Electric vehicles assumed to reach following share by 2050: 100% for 2-wheelers; 60% for passenger light duty vehicles; 30% for buses and trucks; (this assumptions exceed the rate provided in the IEA (2016a).	The GDP share of industry sector declines from 11.70% in 2014 to 10.70% by 2050; A move towards industrial symbiosis (Liu et al., 2011; Morrow, Hasanbeigi, Sathaye, & Xu, 2014).

sources, the projection methods for energy demand and energy prices. The study also does not analyse possible uncertainties associated with the carbon sink capacity of the forest cover over the planning period.

6.1 Energy Demand and Decarbonisation Rate

Since there are no major differences between the total primary energy supply (TPES) and the total final energy consumption (TFEC) in Bhutan (see sub-section 4.3 of this article), the results and discussion are focussed on TFEC. The final energy consumption exhibits a compound annual growth rate of 5%, 4.3%, 6.4% and 5.3% under the BAU, GNH, HGDP and KBS scenarios respectively. Over the planning period, the energy mix varies among the three major energy groups as shown in Figure 2. The three major energy groups being: 1) fossil energy, 2) biomass, and 3) electricity (which is essentially hydropower). Substantial variations in the energy mix are observed. For instance, in the base year, biomass dominates the fuel mix at 41%, while fossil energy dominates the fuel mix under both the BAU and the HGDP scenarios by 2050. Not surprisingly, hydropower dominates the fuel mix under the GNH and KBS scenarios by 2050 contributing to 48% and 61% of the final energy demand respectively.

The carbon intensity of the final energy demand at 86.41 $kgCO_2eq/GJ$ in 2014, which is lower than that of the present world average at 90$kgCO_2/GJ$ (Rogelj, Luderer, et al., 2015) steadily decreases over the planning period under all the four scenarios. For instance, by 2050 the carbon intensity decreases to 52.55 $kgCO_2eq/GJ$ under the BAU scenario, further decreasing to 33.71 $kgCO_2eq/GJ$ under the KBS scenario. Interestingly under the KBS scenario, the energy system of Bhutan exhibits a decarbonisation rate of 2.6% per year, which is well within the range of 2% to 2.8% per year proposed for a 1.5 °C consistent world (Rogelj, Luderer, et al., 2015).

6.2. Emissions Trajectory

Variations in the energy mix discussed in sub-section 6.1 lead to variations in the emissions levels over the planning period under the four different scenarios; these are shown in Figure 3.

Figure 3 shows that the non-energy sector was the dominant contributor of emissions in 2014, however over the planning horizon oil products and solid fuels become the major contributor to the total CO_2eq emissions. Oil products are mostly consumed in the transport sector, while solid fuels are mostly consumed in the industry sector. This suggest a strong rationale for policy intervention in these two sectors and this article does this with a focus on the transport sector. The two alternative scenarios, KBS and GNH demonstrate the possibility of reducing the dependency on oil products and solid fuels through efficiency improvement in the industry sector and technological changes (switching to electric power) and modal shifting in the transport sector.

The emission trajectories under the four scenarios are shown in Figure 4. The emission level exceeds the sink capacity by 2037 and 2044 under the HGDP and BAU scenarios respectively, indicating the need for policy intervention in order to maintain carbon neutrality as the economy expands over the planning horizon. Under the KBS and GNH scenarios, which are the corresponding emission reduction measures for their parent scenarios, the emissions levels were contained below the sink capacity. Compared to their parent scenarios, cumulative emissions reduce by 34% and 22% under the KBS and GNH scenarios. However, such emissions reduction entails adopting efficient and cleaner technologies in the demand sectors with financial implications, which is discussed under sub-section 6.3 of this article. Although the total emissions increases, the carbon intensity of the Bhutanese economy steadily declines

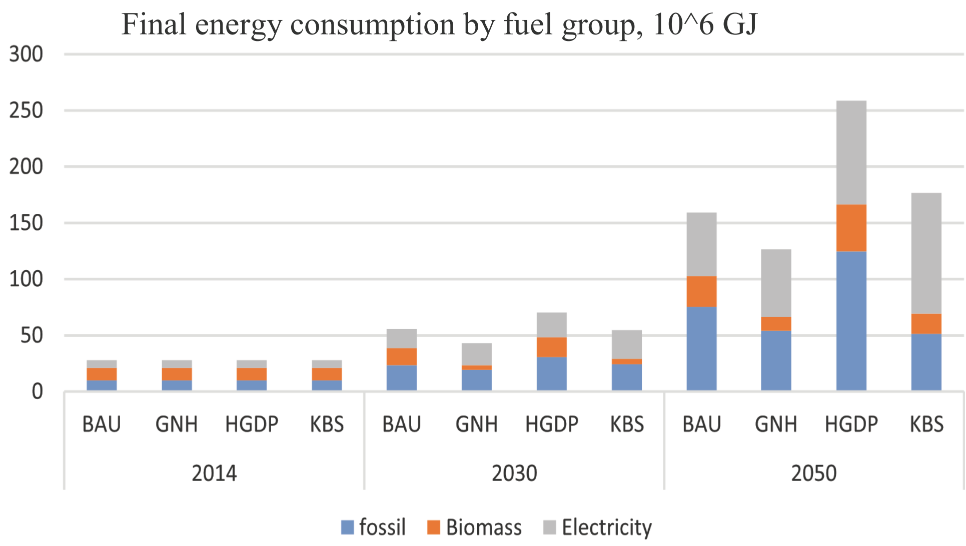

Figure 2. Energy consumption by major fuel group under four different scenarios. Note: BAU (Business as Usual); GNH (Scenario following GNH principle); HGDP (high economic outlook); KBS (knowledge-based society).

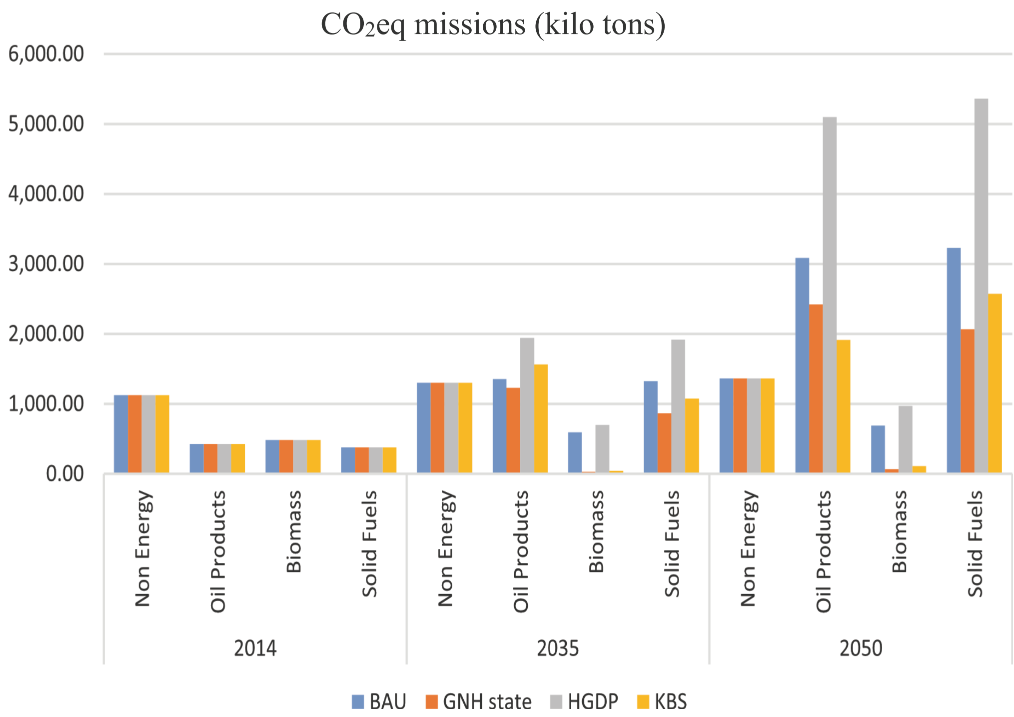

Figure 3. Emission variation by source under different scenarios.

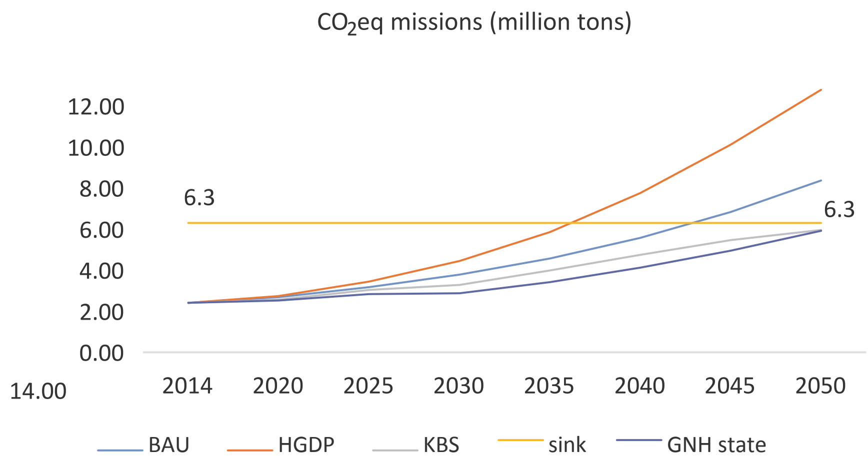

Figure 4. Scenario based CO_2eq emission in Million tonnes.

as shown in Figure 5, demonstrating the potential for a relative decoupling of GDP from environmental pressure, though absolute decoupling will require entirely replacing fossil fuels with renewables-based transport and industry. For instance, under the KBS scenario the carbon intensity of the economy decreases from 2.68 kgCO_2eq/US$ in 2014 to 0.47 kgCO_2eq/US$ by 2050, showing an improvement of 4.7%/year over the planning period.

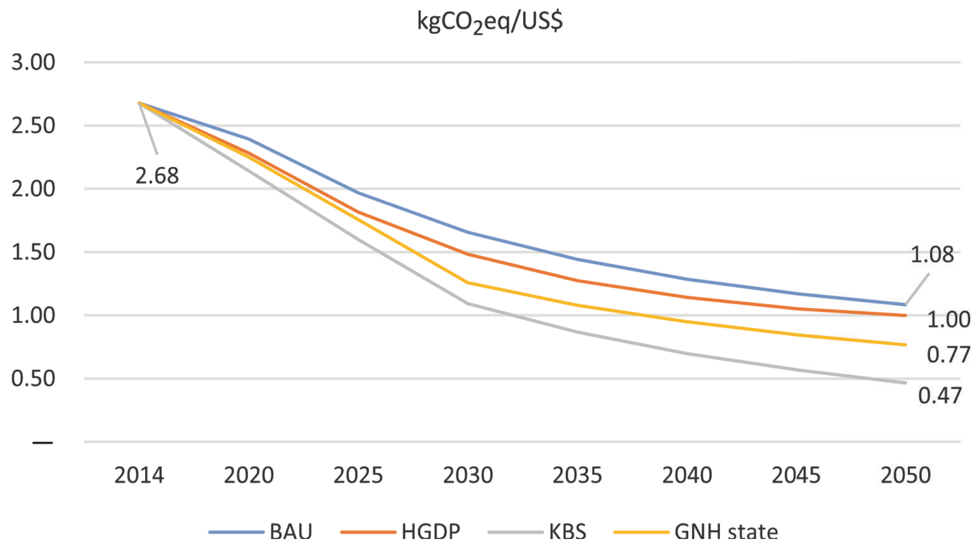

Figure 5. Carbon intensity of the Bhutanese economy.

Such rapid reduction in the carbon intensity is following global trends (Newman, Beatley, & Boyer, 2017) as well as including new technologies in the energy mix as discussed in Sub-Section 6.1.

6.3. The Cost of Taming the Rising Carbon

As discussed in Sub-Section 6.2, the KBS scenario limits the total CO_2eq emission below the sink capacity despite high economic growth, similarly the GNH scenario holds the emission levels from a BAU pathway below the sink capacity. However, they entail transitioning to an efficient industrial production and preferences towards gradual electrification of the transport sector. But it comes with financial implications; there is a cost of carbon mitigation under the KBS scenario and savings from carbon mitigation under the GNH scenario relative to their parent scenarios, which were obtained from the cost-benefit summary report in the result module of LEAP. Table 2 shows the total discounted system cost and the cumulative CO_2eq emissions under the four scenarios. The system cost comprises a demand cost, transformation cost and the net resource cost (cost of export less cost of import). Relative to their parent scenarios, under the two alternative scenarios cost incurred in the demand sector increases, while the cost of resource import decreases. This leads to financial saving of US$ 15.05/tCO_2eq under the GNH scenario relative to its parent scenario, BAU This portion of the result indicates that Bhutan can live up to its carbon neutral pledge with cleaner and advanced technological choices at no cost.

Table 2. Social Cost and CO_2eq emission.

Scenario	**BAU**	**GNH**	**HGDP**	**KBS**
Total discounted system cost, 10̂9 US$	52.78	52.24	66.70	66.90
CO_2eq emission, Million tons	167.43	131.33	219.04	143.67
Mitigation cost (US$/t CO_2eq) relative to BAU	—	(−15.05)	—	—
Mitigation cost (US$/t CO_2eq) relative to HGDP	—	—	—	2.67

However, under the KBS scenario, the cost of carbon mitigation relative to its parent scenario (i.e., HGDP scenario) amounts to US$ 2.67/t CO_2eq. This translates to an additional cost of US$ 5.55 million per year over the planning period, forming 0.043% of the GDP in 2050, which is lower than that estimated for India at 1.5% (GoI, 2014). The reason for the difference could be attributable to various assumptions in the model development and scenario characterisation. Notwithstanding this, pursuing a low carbon economy in India requires decarbonising their electricity sector, which is predominantly coal based, while in Bhutan clean hydropower is already the baseline electricity generation.

With regard to the marginal abatement cost of carbon, a previous study conducted by the Asian Development Bank (Shrestha et al., 2013) for the South Asian countries showed that it varies from a saving of $72.8/t$CO_2$eq to a cost as high as $417.7/t$CO_2$eq depending on the fuel and the technology being substituted by their cleaner and more efficient counterparts. The additional cost under the KBS scenario suggests allocating the limited financial resources towards the carbon neutral goal that could compete with the budget for other pertinent socioeconomic developmental needs. The result supports the viewpoint of Flagg (2015), who calls the carbon neutral pledge as a 'generous public good' (p. 209). However, in a carbon constrained world, where emission reduction targets are being accelerated following the Paris Agreement (UN Framework Convention on Climate Change, 2016), such additional costs could be met through the global carbon market.

6.4. Cost of Mitigation Measures in the Transport Sector

The KBS and the GNH scenarios assume that light rail meets 30% of passenger travel demand by 2050. However, electric vehicles were assumed to follow a different penetration rate in the two scenarios (see Table 1) to contain the corresponding emissions level below the sink capacity. In the GNH scenario, without calling in policies like developing an electric transport system, efficiency improvement in the four industry subsectors along with phasing out of dirty fuels in the residential and service sectors were found inadequate to limit the emissions level within the sink capacity. This is therefore suggesting the crucial role of electrifying the transport sector in Bhutan to live within their net zero carbon budget.

To examine the possible role of light rail transport in supporting the carbon neutral goal, model runs with a 'no LRT case' and 'LRT case' were compared under both the KBS and the GNH scenarios. The model results show that in the 'LRT case' there is a cost saving of US\$51.42/tCO_2eq and US\$ 5.07/tCO_2eq under the KBS and GNH scenarios respectively, while maintaining the emissions level below the sink capacity. This also demonstrates the attractiveness of light rail transport, attributable to its longer operational life and higher passenger carrying capacity despite its high upfront cost. The results show the promises of light rail transport in decarbonising the transport sector thereby leveraging the carbon neutral goal of Bhutan. Furthermore, with a dedicated right of way, light rail can decongest road traffic. A prefeasibility study initiated by UNCRD also found light rail to be promising for urban Bhutan (Hargroves et al., 2017). Furthermore, a detailed project level costs and feasibility are being undertaken in an on-going parallel research activity. LRTs were also found to become cheaper than bus based transport when travel demand grows (IUT India, 2012). The case of transport electrification can also be useful for other emerging countries where oil imports represent a high burden on their GDP.

7. Concluding Remarks and Policy Implications

The long term Bhutan-LEAP modelling exercise provided crucial insights into the carbon neutral goal of Bhutan and its implications for urban planning. The results showed that if Bhutan follows the 2014 BAU energy economy pathway, the associated emissions will exceed the sink capacity by 2044 and the aspiration for a high economic outlook can potentially derail Bhutan's carbon neutral path as early as 2037 if a similar BAU energy economic system gets locked-in. This is suggesting the need for policy intervention if Bhutan is to live within its carbon neutral budget.

The urban planning implications are that electrification of transport is needed and this requires some interventions such as those outlined by (Newman, Davies-Slate, & Jones, 2017). The model results indicate that there is economic benefit arising from introducing environmentally beneficial policies to maintain its carbon neutral status following a BAU pathway. Furthermore, even under the high economic outlook, the cost of carbon mitigation to hold the rising emissions is US\$ 2.67/tCO_2eq only. Nonetheless, Bhutan's hydropower-based electricity generation along with extensive forest cover seem to be the comparative advantage at present and together provide a future bastion of hope to uphold its carbon neutral goal. The hydropower provides clean electricity and the forest cover provide ecosystem support as well as acting as a carbon sink. These features will need to be preserved into the future.

This study could be useful for the Bhutanese policy makers as the country strives to mainstream its low carbon strategy while it pursues a GNH paradigm and aspires to a better living standard. The article could be useful for emerging countries with similar aspirations to that of Bhutan to grow their economy with less emissions, though Bhutan pursuing GNH is unique in that it has shaped its policy making towards social and environmental goals as well as economic development. This article shows that GDP, GHG and GNH can be integrated under scenarios that also invite intervention, especially with electrified transport options. The article suggests there are hopeful scenarios that can be developed for emerging nations like Bhutan to meet the 1.5 °C agenda along with the SDG's.

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Conflict of Interests

The authors declare no conflict of interests.

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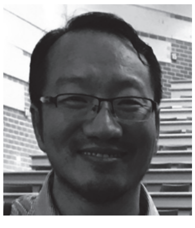
About the Authors



Dorji Yangka is a PhD student at the Curtin University Sustainability Policy Institute (CUSP), Curtin University, Western Australia. He has an M.E in Energy Economics and Planning from the Asian Institute of Technology, Thailand. He is from Bhutan, a carbon neutral and a GNH country. His PhD research is on how Bhutan can uphold its carbon neutral pledge as it aspires to be wealthier and happier. His PhD research is a journey through the complex tri-junction of GDP, GNH and GHG. His research hopes to connect the three goals of Bhutan with the wider literature. He is interested in carbon neutrality, low carbon development, energy policy and modelling, environmental intensity of human wellbeing and sustainability.

Peter Newman is the John Curtin Distinguished Professor of Sustainability at Curtin University. He has written 20 books on sustainable cities and sustainable transport. He is the Lead Author for Transport on the IPCC for their 6th Assessment Report. He was awarded the Order of Australia for his services to urban design and sustainable transport.

Annex

A1. Data source

The base year energy consumptions were referred from the Bhutan Energy Data Directory (Department of Renewable Energy, 2015b). In case of techno-economic parameters of demand technologies, Bhutan specific data were used wherever available and the remaining data requirements were surrogated and adapted from the wider literature. For instance, data for transport sector were adapted from: City Bus Service (2015), Department of Renewable Energy (2015b), DoE (2010), Kołoś & Taczanowski (2016), the Ministry of Information and Communications (2015), Shafiei et al. (2017) and Zhu, Patella, Steinmetz and Peamsilpakulchorn (2016). Data for industry sector were obtained from: DoI(2015), Huisingh, Zhang, Moore, Qiao and Li (2015), Kero, Grådahl and Tranell (2016), Liu et al. (2011); Morrow et al. (2014), and NEC & TERI (2016). Similarly data for residential and the commercial sectors were sourced and adapted from: Department of Renewable Energy (2012, 2015a, 2015b) and UNDP (2012). Techno-economic data for existing hydropower plants and on-going hydropower projects were obtained from relevant stakeholders (Druk Green Power Corporation, 2014; Indian Embassy, 2016; MHPA, 2016). Data for wind power plant was imputed from Bhutan Power Corporation Limited (Personal communication, November 21, 2016) and for solar it was imputed from TERI (2015). Learning rates were imputed from Rubin, Azevedo, Jaramillo, and Yeh (2015) and Shafiei et al. (2017).

A2. Data sets for Bhutan-LEAP model

Table A1. Electricity sector key feature, based on BPC (2015).

Particulars	GWh	US cents/kWh*
Export	5179.3	3.36
Import	187.6	3.77
Generation	7166.3	
T&D loss	3.87%	

Notes: *authors' calculation based on BPC (2015). T&D stands for transmission and distribution.

Table A2. GDP and population projection under the BAU scenario.

Year	GDP, 10^6 US$*	Population**
2014	902	745,153
2020	1,324	809,397
2025	1,822	850,976
2030	2,508	886,523
2035	3,453	931,745
2040	4,753	979,273
2045	6,542	1,029,226
2050	9,005	1,081,727

Notes: US$ stands for the U.S. dollar. *See table 1 in the main text for the assumed growth rate; **data for 2014–2030 is from the National Statistical Bureau (2015); from 2035 to 2050, 1% growth rate was assumed.

Table A3. Power plant techno-economic data.

Plant	Capacity, MW	Capital cost (US$/kW)*	Data source
Existing hydropower plant			
CHP	360	646.57	Druk Green Power Corporation, 2014; DRE, 2015b
Kurichu	60	1517.62	
Basochu	64	828.51	
Tala	1020	657.72	
Dagachu	126	1577.75	
Hydro_Micro	8.20	6952.00	
Candidate hydropower plant			
PHPA I	1200	1270.40	Indian Embassy (2016)
PHPA II	1020	1162.22	
MHPA	720	1088.16	MHPA (2016)
Tangsibji	118	1648.06	Druk Green Power Corporation. (2014)
KHP	600	1048.51	
Mega_hydro	4000	1173.60	This study
Other power plant			
Solar	0.12	1626	Department of Renewable Energy (2015b); TERI (2015)
Wind	0.60	4848.85	BPC, Personal Communication, November 21, 2016
Diesel Generator Set	10.7	2500	Department of Renewable Energy (2015b); Oladokun & Asemota (2015)
WTE	3.4	2746	Department of Renewable Energy (2015b)

Note: *authors' calculations based on the available data sources.

Table A4. Monthly electricity generation and consumption in 2014 based on Druk Green Power Corporation (2014) and BPC, Personal Communication, January 2017.

Month	Generation (GWh)	% Peak Generation*	Consumption (GWh)
Jan	243.7	20.3%	169.8
Feb	178.9	14.9%	154.6
Mar	211.4	17.6%	161.7
Apr	232.6	19.4%	166.0

May	458.9	38.2%	172.5
Jun	785.1	65.4%	167.6
Jul	1187.5	98.9%	155.9
Aug	1200.8	100.0%	164.3
Sep	1162.6	96.8%	157.0
Oct	767.9	63.9%	168.7
Nov	411.5	34.3%	175.1
Dec	306.1	25.5%	191.7

Note: *authors' calculations to construct hydropower availability curve.

Table A5. Cooking and heating end-use technology in the residential and service sectors UNDP (2012); Yangka & Diesendorf (2016).

Device	US$/device	Life (years)	Efficiency
Wood cook stove	5.69	5	10
Efficient wood cook stove	135.45	5	25
LPG/biogas stove	46.34	5	85
Electric stove	43.9	5	90
Efficient wood heating stove	189.66	5	75
Electric heater	57.98	5	90
Kerosene heater	203.25	5	45
Wood heating stove	56.90	5	12

Table A6. Household electric appliances, based on (Department of renewable Energy, 2015a, 2015b)

Device	US$/Device*	Life
Fridge 2-star	268.29	5 years
Fridge 3-star	284.55	5 years
Washing m/c semi-auto	240.65	5 years
Washing m/c auto	256.91	5 years
60Watt incandescent lamp	0.16	1200 hours
14Watt CFL	1.95	10000 hours
42Watt Fluorescent lamp	4.55	10000 hours
7Watt LED	7.31	50000 hours

Notes: *authors' calculation derived from the referred data sources.
CFL — compact fluorescent lamp; LED stands for light emitting diode.

Table A7. Cost of passenger vehicle (IUT India, 2012*; RSTA, Personal Communication, October 19, 2016; Zhu et al., 2016).

Vehicle	Cost (US$)
Electric-cars	20,488
Light vehicle_gasoline	7,073.17
Light vehicle_diesel	29,268.29
Electric-bike	945.59
Diesel bus	39,204.75
Electric-bus	300,000.00
Light rail* (30 years life; 0.3MJ/pkm; 242 persons/coach)	1.62 million

Table A8. Transport sector technology characteristics, based on DoE (2010), Ministry of Information and Communications (2015), Yangka and Diesendorf (2016) and Zhu et al. (2016).

Passenger transport

Vehicle type	Fleet	km/litre	Occupancy (person/vehicle)	mp-km/year
2-wheeler	9988	53.8	1.6	36.1
Taxi	4109	15	2.93	297.6
Light	41924	15	2.55	524.8
Bus	354	3.27	18.85	696.0

Freight transport

Vehicle type	Fleet	km/litre	Average capacity (tonnes/vehicle)	mt-km/year
Heavy	8120	3.7	6	1933.78
Medium	1392		3	392.73

Note: mt-km stands for million tonnes kilometre; mp-km stands for million passenger kilometre.

Table A9. Freight transport technology, based on DoE (2010) and ETSAP (2010).

Freight vehicle	Diesel heavy truck	Heavy electric-truck*	Diesel light truck	Light electric-truck*
MJ/vehicle-km	7.46	−76%	3.92	−77%
Capital cost	32,000	406%	20,292	297%
kWh/vehicle-km		0.49		0.49
O&M cost	0.13	−82%	0.0561	−76%

Note: *authors' calculation based on ETSAP (2010).

Table A10. Transformation processes other than power generation, data imputed based on DoI (2015), Department of renewable Energy (2015a) and DRE & UNDP (2014).

Process	Capital cost	O&M cost	Life (years)	Production in 2014 (tonnes)	Resource potential
Coal Mining	49.59 (US$/ton)	82.62 (US$/ton)	50	121,891.00	1.9 Mt
Biogas production	18.96 (US$/GJ)	NA	30	898.45	633,756.19 GJ
Briquette making	4.05 (US$/GJ)	5% of capital cost	20	367.40	6,832.80 GJ

Table A11. Industry sector techno-economic data.

			US$/tonnes*			
Industry	**SEC (kWh/tonnes)**	**Production (tonnes)**	**Capital cost**	**O&M cost**	**Life (years)**	**Data source**
Cement	132.71	525,240.00	113.04	60.39	20	DoI (2015), Department of Renewable Energy (2012, 2015a)
BCCL	5,340.58	32,340.48	812.38	842.76	20	
Steel	825.50	196,172.22	46.07	335.40	20	
Ferro Alloys	9,000.00	105,050.00	660.98	895.05	20	

Note: *authors' calculation based on the listed data sources.

A3. Demand Projection

LEAP expression builder allows creating expressions for linking one branch to the other. For instance, the following expression syntax

GrowthAs(Branch:Variable, Elasticity)

relates the current branch (containing the above expression syntax) to the other branch which contains the independent variable that is assumed to drive the growth of the dependent variable in the current branch within the elasticity value specified by the modeller. In the Bhutan LEAP model, the above expression syntax translates to the following equation when invoked to project demand in the demand branches.

$$\text{Demand}(t) = \frac{\text{Demand}(t-1) * \text{driver}(t)}{\text{driver}(t-1)} \qquad \text{(Eq. (A.1))}$$

The driver is the chosen macroeconomic parameter (such as GDP, per capita GDP, population, number of households, etc.) provided under the 'key assumption' branch.

Table A12. Projected demand.

Sector	Unit	2014	2020	2025	2030	2035	2040	2045	2050
Transport sector									
Passenger travel bp-km		1.93	2.84	3.91	5.39	7.43	10.24	14.11	19.45
Freight travel bt-km		2.34	3.67	5.34	7.77	11.31	16.46	23.97	34.89
Industry sector									
BCCL	kt	32.3	40	57.6	81.7	113.7	155.7	209.4	276.9
Ferro Alloys	kt	106.8	132.1	190.4	269.7	375.6	514.1	691.6	914.5
Iron and Steel	kt	196.2	242.7	349.7	495.4	689.8	944.2	1,270.3	1,679.8
Cement	kt	525.2	649.8	936.3	1,326.3	1,847	2,528.1	3,401.3	4,497.6
Residential and Service sector									
Residential (Thousand HH)		164.13	175.2	185.1	195.5	206.52	218.13	230.4	243.35
Service (Million US$)		320.56	502.5	731.6	1,065.0	1,550.5	2,257.2	3,285.9	4,783.6

Table A13. Fuel price projection, based on Department of Renewable Energy (2015a) and US Energy Information Administration (2016).

Fuel	Unit	2014	2020	2025	2030	2035	2040	2045	2050
Diesel	US$/lt	0.82	1.29	1.49	1.74	2.00	2.31	2.67	3.09
Gasoline	US$/lt	0.95	1.49	1.72	2.01	2.31	2.67	3.08	3.56
Kerosene (Domestic)	US$/lt	0.21	0.34	0.39	0.46	0.52	0.61	0.70	0.81
Kerosene (Industry)	US$/lt	0.77	1.22	1.41	1.64	1.89	2.18	2.52	2.92
Aviation Turbine Fuel	US$/lt	1.00	1.58	1.82	2.12	2.44	2.82	3.26	3.77
LPG	US$/kg	0.42	0.67	0.77	0.90	1.03	1.19	1.38	1.59

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Figure 12. Industrialisation and rising personal transport (photo source: Thinley Namgay with permission)

Publication 5 - Carbon neutral Bhutan: Sustaining carbon neutral under growth pressures

Yangka, D., Rauland, V. & Newman, P. (2018). Carbon neutral Bhutan: Sustaining carbon neutral under growth pressures (submitted).

This is an exact copy of the submitted paper referred to above.

Carbon Neutral Bhutan: Sustaining carbon neutral under growth pressures.

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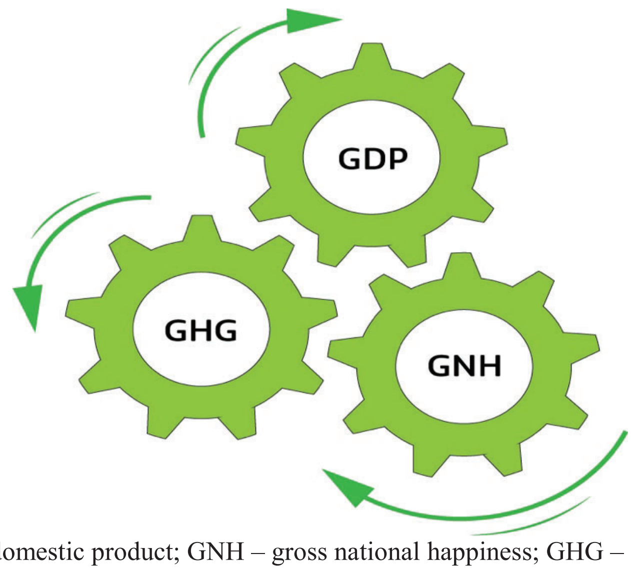
Bhutan is famous for its Gross National Happiness (GNH) indicator (RGoB, 2012; Schroeder & Schroeder, 2014; Ura, 2015). It is less well known for its status as being one of the few carbon neutral countries in the world. It achieved this status in 2011 (NEC, 2012) and reaffirmed it in 2015 for the Paris Agreement (RGoB, 2015). There is potential for Bhutan's choice of pathway to represent a strong model for any emerging nation to follow as the pressure to go beyond simply reducing emissions and reach carbon neutral (CN) status is set to grow (IPCC, 2018; Robinson & Shine, 2018; Rockström et al., 2017). However, nations and cities looking to achieve CN status must demonstrate how this status can be enshrined in strong economic policy. As well as its CN and GNH commitments, Bhutan has a policy to become a middle-income country by 2023, which means substantial increases in GDP.

This paper looks at how Bhutan will need to transform its energy system if it is to continue to maintain its CN status in the light of competing demands for economic growth and GNH. The challenge is how to manage environmental goals when faced with competing economic and social goals, one that has been set since the Brundtland Commission (WCED, 1987) and now the United Nation's Sustainable Development Goals (United Nations, 2015). This nexus is the challenge for every nation, but especially emerging nations experiencing growth pressures. It calls for economic analysis that can integrate the three interconnected goals for GNH, GDP and GHG, as shown in Figure 1.



(GDP – gross domestic product; GNH – gross national happiness; GHG – greenhouse gas)

Figure 1. The three Gs – the interconnected goals.
Adapted from (Yangka, Newman, Rauland, & Devereux, 2018)

Bhutan's carbon neutral challenge

Several countries have pledged to become CN (Flagg, 2015), although Bhutan is one of the very few that has actually achieved this status. Carbon neutrality has many definitions, but the one Bhutan has used is based on neutralising greenhouse emissions with forest-based carbon sequestration (Yangka, Newman, et al., 2018). The broadly accepted intention of CN is to balance the carbon released into the atmosphere with the inputs and outputs of a product or service. It requires the measurement, reduction, and finally offsetting of emissions (Rauland & Newman, 2015; UNEP, 2011). Birchall (2014) considers CN to be an extension of long-term climate policy and GHG mitigation strategies that should be applied at the national level. While there is an International Standard 14067:2018 for the carbon footprint of products, there is no universal definition or framework for CN at the national level, and many of the countries that have pledged carbon neutrality have not clearly defined it, although in some cases broader strategies for achieving it have been outlined (FDRE, 2011; Flagg, 2015). The definition used here is the simplest for developing policy scenarios. While some may argue that it should include the export of renewable hydropower (to India), this would imply that the import of embedded carbon in many consumer items is well understood, which it is not; it is in fact very complex. This paper will therefore examine scenarios that fit within the carbon neutralising sink capacity provided by Bhutan's current and growing forests.

Whether Bhutan can remain CN in perpetuity is uncertain. The Climate Action Tracker (2015) expressed concern over rising GHG emissions in Bhutan. Yangka (2013) also cast doubt on the long-term carbon neutrality of Bhutan based on the extrapolation of carbon emission levels from 2005 to 2050, although this was without scenario analysis. Thus, the challenge for Bhutan is how it can remain CN under growth pressures (Yangka, Newman, et al., 2018).

This paper describes the background to Bhutan's energy system, the context of earlier studies conducted on energy modelling and emissions reduction, then gives the results from seven economic scenarios created to examine the nexus growth pressures and their policy recommendations. A separate Methods section shows how the modelling was done.

Energy system of Bhutan

Bhutan is endowed with 24,000 MW of hydropower potential and 71% forest cover. It lacks fossil fuel reserves, except for a limited amount of sub-bituminous coal (DRE, 2015). This pattern of natural resource endowment provides a natural advantage for Bhutan in upholding its CN declaration in a carbon-constrained world. However, Bhutan also has very energy intensive and highly polluting industry sectors, including cement, iron and steel, calcium carbide and ferrosilicon industries. Despite its small economy, Bhutan was also listed, along with eleven other countries around the world, as a key economy for silicon production (Kero, Grådahl, & Tranell, 2016). Bhutan also has a very rigid transportation system, in which commuters do not have the choice of different modes of transportation, since there are no railways or waterways, and limited air transport. It relies predominantly on a surface road transport system based on trucks, cars and motorbikes. This is dependent on 100% imported diesel and gasoline from India. In 2014, the base year of this study, both the transport and the industry sectors contributed 30% each to the total GHG emissions.[13] This is expected to increase substantially over the planning period of this study.

Total energy demand in Bhutan increased from 402 ktoe in 2005 (DoE, 2007) to 650 ktoe in 2014 (DRE, 2015) leading to an increase in the per capita energy consumption from 0.63 toe to 0.87 toe. Between these two periods, energy consumption in the transport and industry sectors witnessed a growth of 200% (DRE, 2015). In 2014, fossil fuels (petroleum and coal) formed the largest share at 37%, followed by biomass at 36% and hydropower at 28%. At the sector level, industry and transport together formed 56% of the total energy consumption.

Previous energy modelling work

Studies covering long-term integrated energy-economy modelling and policy analyses for Bhutan are limited (see Yangka and Newman (2018)). Shrestha, Ahmed, Suphachalasai, and Lasco (2013) highlighted a number of options to reduce GHG emissions, while Yangka and Diesendorf (2016) quantified the benefits of expanding electric cooking in terms of reduction in CO_2 emissions and other local air pollutants. The National Low Carbon Strategy for Bhutan (NEC, 2012) is the only report that discusses CN in Bhutan. The strategy (NEC, 2012) was developed using a Microsoft Excel based model with a low GDP growth rate of 5.7%, which does not include a cost module. The analyses assumed saturation of travel demand and industrial output by 2020. Such assumptions invariably lead to lower emission levels, thereby overlooking the need to foresee the challenges of CN development and the subsequent policy implications as the country grows. Only one study provides information on the probable costs of Bhutan's CN pathway into the future (Yangka & Newman, 2018), but it does not have the full scenarios outlined here. The method in this study is based on the Long-range Energy Alternatives Planning (LEAP) model, which enables the nexus between carbon neutral, happiness and economic development goals to be analysed under various growth pressures. Methods of analysis and different scenarios are outlined in a separate Methods section below, with further details provided in the Appendix.

Results and discussion

The Bhutan–LEAP model runs the seven scenarios outlined in Table 1 in two groups: Group A is a baseline of essentially present growth with high and low growth variations, including the present Nationally Determined Contributions; and Group B indicates how the CN status is retained under growth pressures and what this will take in terms of technology and policy.

Table 1. Group A and Group B scenarios

Group A (baseline) scenarios	*Group B (Carbon neutral) scenarios*
1) Business As usual (BAU)	5) Carbon Neutral BAU (CNBAU)
2) High economic growth (HGDP)	6) Carbon Neutral HGDP (CNHGDP)
3) Low economic growth (LGDP)*	

4) Nationally Determined Contribution (NDCplan)

7) Carbon Neutral NDC (CNNDCplan)

Note: Group B forms the corresponding carbon neutral counterpart of the group A scenarios;
* CO_2e emissions remain well below the carbon neutral budget of Bhutan
(see section on emission trajectory).

Energy and electricity demand

During the planning period, energy demand increased at a compound annual growth rate (CAGR) of 7% under the HGDP scenario, 5% under the BAU scenario and 4.5% under the NDCPlan scenario. As expected, the energy growth rate decreases under the corresponding CN scenarios where energy efficiency measures are deployed. Over the planning period, the share of electricity in the final energy demand parameter will steadily increase, as predicted for most countries (IEA, 2016). The total electricity demand will increase at a CAGR of 6.1%, 8.1% and 9.0% under the BAU, HGDP and CNHGDP scenarios and, consequently, the per capita electricity consumption will increase at 4.9%, 7.0% and 7.8% under the corresponding scenarios. The high growth rate of electricity demand under the CNHGDP is attributed to electricity replacing other fuels in the demand sector, which consequently leads to increased power generation, but a reduction in emissions (discussed further below). Total electricity demand over the planning horizon under various scenarios is shown in Table 2.

Table 2: Electricity demand under different scenarios (Billion kWh).

Scenarios	2014	2020	2025	2030	2035	2040	2045	2050
BAU	1.89	2.37	3.36	4.70	6.53	8.91	11.96	15.79
CNBAU	1.89	2.37	3.36	4.65	6.54	9.06	12.32	16.48
HGDP	1.89	2.50	3.92	6.10	9.25	13.60	19.75	28.71
CNHGDP	1.89	2.86	4.80	7.74	11.73	17.41	25.63	37.88
NDCPlan	1.89	2.39	3.36	4.62	6.34	8.61	11.55	15.29
CN_NDCPlan	1.89	2.61	3.87	5.52	7.40	9.86	13.00	16.96
LGDP	1.89	2.25	2.88	3.57	4.31	5.03	5.77	6.62

Emission trajectory

The trajectories for the total GHG emissions under each scenario in Group A and B are shown in Table 3.

Table 3: CO_2e emissions (MT-million tons) under each scenario

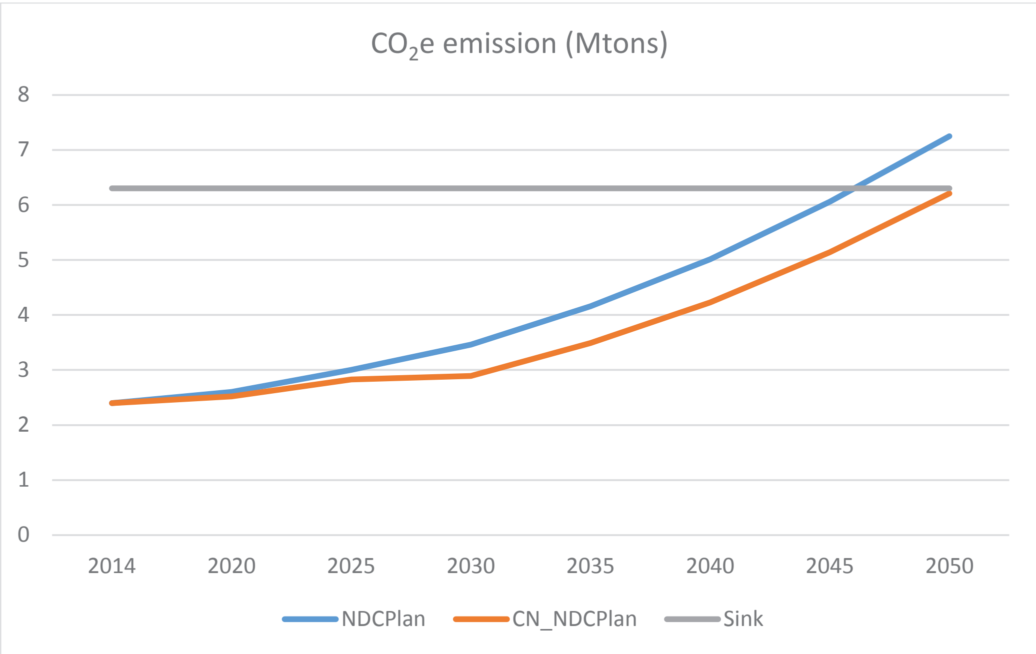
Group A scenarios	*2014*	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
BAU	2.40	2.67	3.16	3.76	4.54	5.54	6.78	8.28
HGDP	2.40	2.74	3.44	4.43	5.82	7.70	10.28	13.97
NDCPlan	2.40	2.60	3.00	3.46	4.16	5.01	6.06	7.25
LGDP	2.40	2.61	2.92	3.21	3.49	3.73	3.95	4.19
Group B scenarios								
CNBAU	2.40	2.52	2.82	2.89	3.42	4.06	4.76	5.58
CNHGDP	2.40	2.51	2.87	2.92	3.53	4.23	5.04	6.00

CN_NDCPlan	2.40	2.52	2.83	2.89	3.49	4.23	5.14	6.21

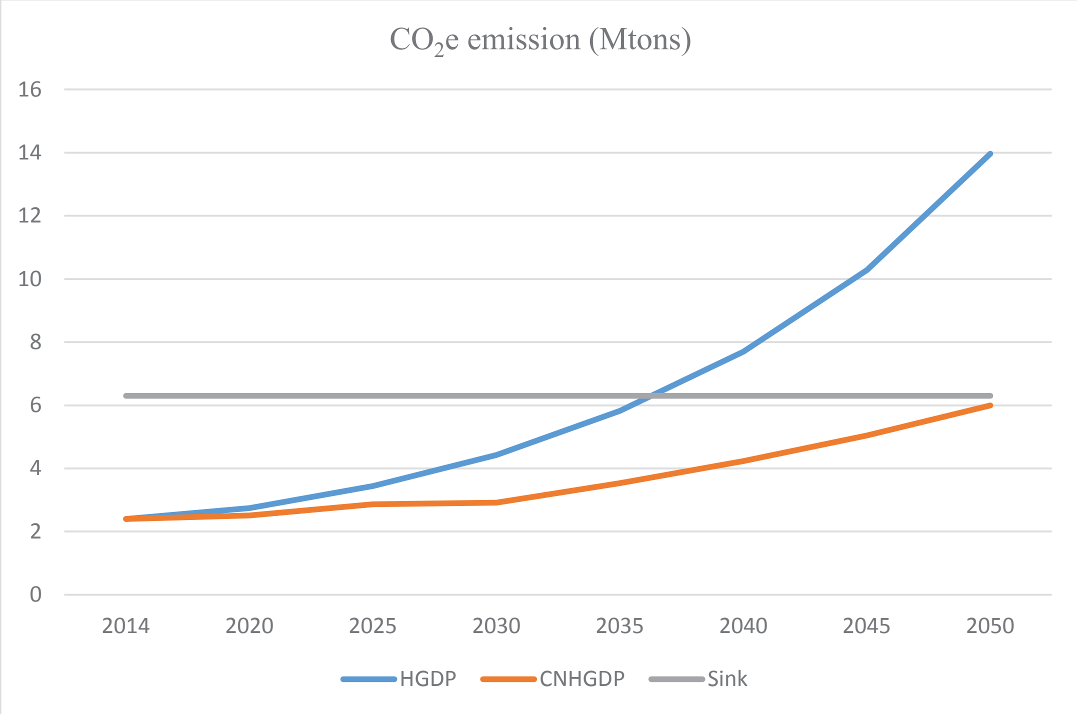
The CN sink capacity of 6.3 MTs of CO_2e is exceeded in most of the Group A scenarios, especially HGDP, but also in the NDCPlan scenario. The emissions level exceeds the sink capacity by 2037 under the HGDP scenario, by 2044 under the BAU scenario and by 2047 under the NDCPlan scenario. These results suggest the need for intervention to limit the carbon emissions within the CN sink capacity. Without mitigation measures, the emissions level remains below the sink capacity only if there is a low economic growth outlook (ie. LGDP). However, the Government of Bhutan does not envision such a lean horizon, as, like most emerging nations, the Bhutanese dream of improving their living standard in the 21st century when humanity moves out of poverty towards a more sustainable and comfortable livelihood as suggested by the Sustainable Development Goals (Sachs, 2012). This growth is not in opposition to the happiness agenda because the policy commitments to fairness, sufficiency and wellbeing measured by the Gross National Happiness criteria (Yangka & Newman, 2018) also result in increases in GDP.

The Group B scenarios show what mitigation measures can do to keep Bhutan within its sink capacity and thus sustain its carbon neutral status into the future. The results show that these measures can keep the emissions within the carbon sink capacity, but at varying mitigation costs, as explained further in the next section. The results are summarised with their CN counterpart in Figures 2 a), b) and c).

a) BAU and its carbon neutral counterpart



b) NDC Plan and its carbon neutral counterpart



c) HGDP and its carbon neutral counterpart

Figure 2. Carbon neutral scenarios under different growth pressures.

It can be seen that the total CO_2e emissions steadily rises in all the scenarios; however, as can be seen, the rise is lower in the corresponding CN scenarios due to fuel switching and energy efficiency measures. Figure 3 shows the role of reducing carbon intensity in three key scenarios; although the total emissions increase, the carbon intensity of the Bhutanese economy steadily improves from 2.67 $kgCO_2e$/US$ in the base year to 0.41$kgCO_2e$/US$ by the end of the planning horizon in the CNHGDP scenario. This demonstrates the potential of the Bhutanese economy to decouple its growth from environmental pressure while meeting its CN goal (Newman, 2017). The question then becomes whether or not this is feasible.

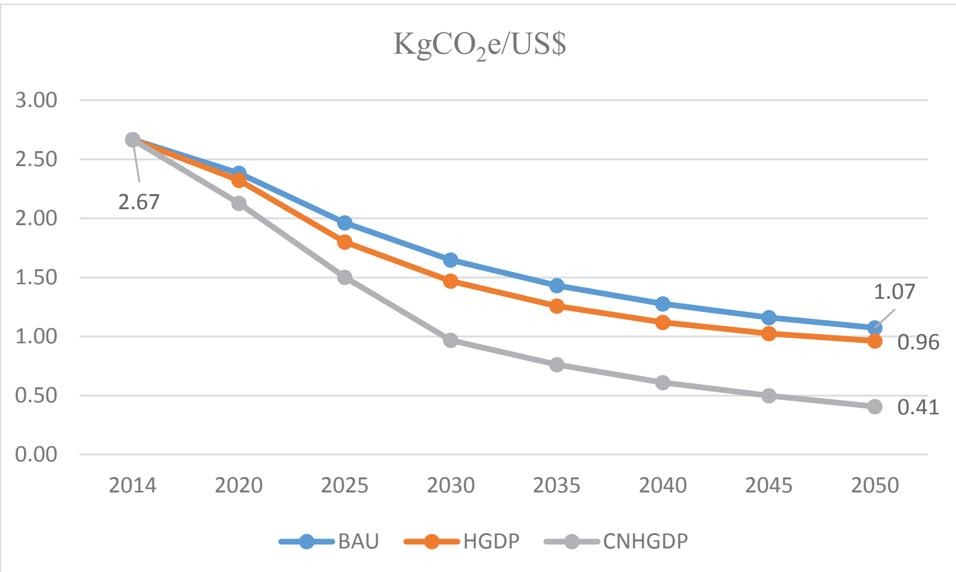


Figure 3. Carbon intensity of the Bhutanese economy.

The cost of emission reduction

The LEAP model calculates total system cost from a societal perspective, where various scenarios can be compared based on the Net Present Value (NPV). The total system cost comprises demand costs, transformation costs and net resource costs.

Within the limits of the mitigation measures specified and selected (see Table 1, Methods section), the cost to Bhutan of mitigating carbon emissions so as to hold the emissions level below the sink capacity, will be US$2.07/tonne CO_2e in the CNBAU scenario and US$37.93/tonne CO_2e in the CNHGDP scenario, as there is a lot more carbon to be removed and this is more difficult to do technologically (more of the expensive F8050). Under the CN_NDCPlan scenario (which assumes certain measures will be taken in advance of the CN measures as per Table 2, Methods section), Bhutan has the potential to save US$ 8.07/tonne CO_2e. This low cost is due to the no-regret/cost savings mitigation measures (IS + MF30), and highlights the benefits of early action.

The high cost associated with the CNHGDP scenario highlights the issues relating to high growth. To maintain its carbon neutral status following the NDCPlan scenario, Bhutan could be saving US$7.2m/yr over the planning period (i.e. to 2050) and in the low growth BAU scenario, Bhutan would only bear an annual average cost of US$ 2.2m/yr. However, under the high growth scenario, which would appear necessary for the middle-level economy and higher GNH objectives, Bhutan would need to spend US$95m/yr. On the other hand, this is just 2% of GDP, due to the extra opportunities created by such growth. High economic growth creates the need for more rapid change in carbon neutrality measures, as well as the means to do them.

This suggests a need to explore climate financing options to help to cover the additional costs under the low growth and high growth scenarios in the early phases and adjusting as growth changes. Under both scenarios, Bhutan would need to ensure the opportunities created from economic growth can include the technological switches required to maintain carbon neutrality. This will need to include both public and private commitments to these changes. The biggest challenge is switching from oil-based technologies to electric technologies, so that they can be hydro-based. In particular, the electric transport system entails large costs attributable to the relatively high capital cost of electric trucks and an electric passenger transport system; however, these systems are all reducing rapidly in cost. For example, an electric public transport system can be introduced that removes many cars from the road system (Glazebrook & Newman, 2018) with technologies such as the Trackless Tram (involving cross-over autonomous rail technologies) at around one-tenth of the cost of urban rail as no track work is required (Newman et al., 2019). Such options increase GNH and GDP, as well as reducing GHG. Such disruptive technologies are not included in the modelling.

Conclusions

This study adds to the literature on CN development at the national level, using long-term energy-economy modelling for the case of Bhutan. The study has shed light on some key concerns for Bhutan if it intends to sustain its CN status under growth pressures. This paper has shown that despite having clean hydroelectricity, if Bhutan follows the 2014 BAU energy-economy pathway, the GHG emissions arising from it will exceed the sink capacity by as early as 2037 under high economic growth due to its industry and transport GHG. Low growth will mean the CN goal is easier to maintain, but it will not achieve its other goals.

The LEAP model suggests that Bhutan can leapfrog existing carbon intensive technologies by adopting efficient technologies and fuel-switching options to curb its rising carbon emissions, especially in the industry and transport sectors. The model runs for the various scenarios show that energy system changes in Bhutan are possible that would allow it to maintain its CN status, although there are additional costs. Under the CN_NDCPlan scenario, Bhutan will achieve financial savings as well as sufficient emissions reduction to maintain CN. However, this does not reflect the high growth scenario that is more likely, due to Bhutan's aspiration and policy of becoming a middle-income nation by 2023 and its policy of maintaining its fairness, sufficiency and wellbeing, as measured by GNH. Under these high-growth pressures, Bhutan will need to ensure it electrifies industry and transport as part of its economic growth strategy. The costs are not prohibitive, just 2% of GDP, and the results achieve GNH and GDP commitments. Disruptive innovations in transport and industry may make this even easier as reduced cost solutions for electric transport and industry electrification suggested for Bhutan are likely to be part of the agenda of economic growth in all emerging nations under growth pressures (IPCC, 2018).

This study therefore recommends that Bhutan develop a CN strategy that can avoid the structural path dependence and lock-in of carbon intensive infrastructure by enabling new CN technologies for simultaneous growth in GDP and GNH with reductions in GHG. This will require the Bhutan government to identify potential barriers to deploy these options and seek access to finance (Yangka, Rauland, & Newman, 2018). Such development issues are central to the future planning of any emerging nation and this study shows that it is possible to maintain CN status under both low and high growth pressures.

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Author contributions
D.Y. collected the data, conducted the scenario modelling and analysis; D.Y. and V.R drafted the initial paper; P.N. provided additional context and editing for the paper; all authors contributed to structuring and finalising the paper.

Competing interests
The authors declare no competing interests.

Methods

This study used the Long-range Energy Alternatives Planning (LEAP) model to conduct an integrated energy system analysis of Bhutan through scenario modelling. LEAP is an energy system model developed by the Stockholm Environment Institute (SEI), which is flexible, user-friendly and free for emerging economies (Heaps, 2016). The objective function of LEAP is cost minimisation from a societal perspective. LEAP can support combinations of top-down and bottom-up approaches to energy system modelling (Ouedraogo, 2017), and it is capable of modelling issues beyond technological choices, and thus is useful for capacity building applications (ESMAP, 2012) and to assess Sustainable Development Goal issues (Nilsson et al., 2012; Ouedraogo, 2017). The LEAP model is increasingly being used for low emission development (LED) studies, notably in emerging economies (Emodi, Emodi, Murthy, & Emodi, 2017; ESMAP, 2012; Kumar & Madlener, 2016; Ouedraogo, 2017; Shakya, 2016; Subramanyam, Kumar, Talaei, & Mondal, 2017; Thuy & Limmeechokchai, 2015; Yophy, Jeffrey, & Chieh-Yu, 2011). In building the LEAP–Bhutan model, its optimisation capability was used for electricity generation expansion, along with its simulation features. The simulation model gives more flexibility to the user to incorporate practical issues.

Scope and limitations

In this study, discussions and analysis are limited to those topics that are deemed pertinent to understanding the overall energy mix, the associated cost and GHG emissions, purely from a CN perspective. For this reason, the trend and implications of local air pollutants are not analysed, as the focus is primarily on GHG emissions represented by carbon dioxide equivalent (CO_2e), consisting of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The study also does not incorporate embodied carbon emissions, or costs associated with infrastructure, houses and buildings. Learning rates[14] are assumed only for disruptive, rapidly expanding technologies, such as wind, solar photovoltaic and electric transport systems (see Appendix).

It should also be acknowledged that LEAP does not provide the feedback loop of price adjustment arising from a specific mitigation measure (ESMAP, 2012). Furthermore, this study does not analyse the implications of changes to forest cover

[14] Learning rates refer to a percentile value which implies reduction in the cost of technologies when its production amount doubles

and its sink capacity is taken as reported by the National Environment Commission (NEC, 2011). The Constitution of Bhutan has mandated that the state must ensure a minimum of 60% forest cover for all time and for now, forest cover in Bhutan is being maintained at 71% (MoAF, 2017).

This study uses the baseline data sets openly accessible in Yangka and Newman (2018), which were collected from various sources for the same research project. However, the scope, scenario formulations, and the issues analysed and discussed are distinct from the earlier work.

Structure of Bhutan–LEAP model and general assumptions

The Bhutan–LEAP model is comprised of four main branches: Key Assumptions, Demand, Transformation and Resources, which are further subdivided as per the research requirement and data availability, as shown in the Appendix (A1). Key Assumptions consist of the macro-economic parameters, which are deployed as drivers of future energy consumption and are linked at the activity levels under each of the demand sectors. The Demand branch consists of four major demand sectors: Residential, Commercial/Services, Industry and Transport. These are further disaggregated into sub-sectors and end-use type, purely based on data availability. Energy consumption in the agriculture sector in Bhutan is negligible compared to other sectors, hence it is accounted for under 'Others' in the commercial sector. The transformation branch is comprised of energy conversions, such as electricity generation, coal mining, among others. The Resources branch includes primary energy sources and secondary energy sources, whether imported or indigenous.

The planning period extends from 2014 to 2050. The emission factors and the global warming potential (GWP) were taken from the technology and emission database (TED) of LEAP. For details on the general assumptions adopted in this study see Appendix (A2). Further information on the data sets and their sources are provided in Appendix (A3).

Distinct features of Bhutan–LEAP model

The Bhutan–LEAP model is relatively simple in that there are no fossil fuel extraction and conversion processes such as oil refineries, except for coal mining, biogas production, briquette making and the hydropower system. On the demand side, there is no rail system or waterways for transport, and limited domestic airways. Petroleum products are consumed in all demand sectors, and are imported from India as Bhutan has no oil reserves or oil refineries.

It was noted that there are distinct energy usage patterns in the urban and rural residential areas of Bhutan, which may require a unique policy intervention; however, such disaggregated data are not available in the Energy Data Directory (DRE, 2015b). Further, in the Energy Data Directory, the Industry sector was categorised based on electrical voltage levels, such as high, medium and low voltage, irrespective of the production system. In this study, the Industry sector is categorised based on industrial output, which was deemed more appropriate for assessing technological options for CN development. Also, in the Industry sector, this study takes into account charcoal, woodchips and bamboo chips that are being used as reducing agents and as raw materials in the production process, which were not provided in the Energy Data Directory. These goods are mostly imported from India and the required data are synthesised from Department of Industry (2015) and Revenue and Customs (DRC, 2015).

Energy resource and supply

The LEAP model requires reserve levels for exhaustible resources and yield levels for renewable resources. Such data were calculated from the Bhutan Energy Data Directories (DoE, 2007; DRE, 2015b). Techno-economic parameters for existing and candidate power plants were obtained from various data sources (see Appendices (A2) and (A3)). The generation profile of hydropower plants was constrained by the availability curve, based on the actual monthly electricity generation obtained from the Druk Green Power Corporation (2014).

With regard to the impact of climate change on precipitation levels in Bhutan, NEC (2011) reports that the mean annual precipitation will decline by 2% in the dry season and increase by 4-8% in the wet season – a net increase in the precipitation level. It was assumed to have a corresponding direct impact on the hydrological condition thus affecting hydropower generation as run-off characteristics are not known with any detail. Such issues were modelled by varying the hydropower availability curve, which in turn affects the hydropower generation profile. No significant changes were observed in the power generation level. This result also aligns with the belief of the key people in the energy sector of Bhutan, who are hopeful that climate change will have an insignificant impact on Bhutan's hydropower generation profile for a long time (Yangka, Rauland & Newman, 2018). The impact of varying precipitation levels on the river flow and, therefore, hydropower generation are complex, and is largely dependent on the climate models used, the timeframe considered and a host of other factors (Shrestha, Bajracharya & Babel, 2016). This could be exacerbated by sediment build up, thus warranting separate research specific to Bhutan. Nonetheless, the design and construction of hydropower dams in Bhutan are said to have incorporated features which are resilient to glacier lake outburst floods (GLOF) that are attributed to climate change (NEC, 2011).

Increasing exports of renewable energy would theoretically increase the sink capacity for Bhutan's emissions, although this is not considered in this analysis due to the need to also include imports of embedded carbon in a range of products. However, as a general climate policy, exporting renewables to India would be of value to both the global carbon agenda and the local economic growth agenda, while increasing imports from the Indian grid is harmful to both.

Projection of energy demand

Population, Household, GDP, per capita GDP and Sectoral Value Added were used as the drivers of energy consumption that are ultimately used to calculate CO_2e emissions; the 'Impact' in this study under the ImPACT formulation, is popularly called the Kaya Identity (IPCC, 2000; Kaya, 1990; US EIA, 2016) for greenhouse gas emissions, and 'T' represents various 'technologies' in the LEAP model. These drivers were also used for modelling the low carbon scenario for India (Anandarajah & Gambhir, 2014) and carbon neutral transport system in Iceland (Shafiei, Davidsdottir, Leaver, Stefansson, & Asgeirsson, 2017). See Appendix (A4) for details. Considering the lack of studies specific to Bhutan to establish an elasticity value between the macroeconomic parameters and the sectoral energy demand, this study assumes an elasticity value of one between the chosen driver and the sectoral energy demand. Yophy et al. (2011) also had used GDP elasticity of energy demand as one for the

Taiwan LEAP model. It was recognised that elasticity values change over time and are brought about by structural changes and energy efficiency gains, which are separately modelled through fuel substitution and efficiency improvements in the LEAP model over the planning period.

Projection of energy prices

The price of domestic biomass energy is assumed to increase at 3% per annum (Yangka & Diesendorf, 2016), and bamboo chips and wood charcoal, which are mostly imported from India for use in the Industry sector, are assumed to rise at 4.1% per annum (Feuerbacher, Siebold, Chhetri, Lippert, & Sander, 2016). The prices for petroleum products (see Appendix (A4), Table A.13) are projected to follow the international oil price and thus are indexed to the price changes calculated from US-DoE (US EIA, 2016). It is reasonable to project the price of petroleum products in Bhutan along with the international oil price projection, since the oil import dependency of India is expected to increase from 74% in 2013 to 91% by 2040, as per the World Energy Outlook Special Report (IEA, 2015). In that report, prices of oil, coal and natural gas in India were projected by linking them to international prices.

Scenarios storyline and carbon neutral measures

Considering Bhutan's rising carbon emissions (NEC, 2011; RGoB, 2015; Yangka, 2013) and the need to keep these emissions within the carbon budget of Bhutan, plausible energy-economy pathways were explored. Raskin, Gallopin, Gutman, Hammond, and Swart (2000) note the benefits of scenario analyses, stating that 'Scenarios enlarge the canvass for reflection to include a holistic perspective over space, issues and time' (p. 3). Thus, numerous scenarios can be imagined and formulated to explore the future. This study deviates from the usual scenario analyses of comparing alternative scenarios to a baseline, in that two groups of scenarios were formulated – Group A and Group B – to provide a clear understanding of the underlying assumptions that drive each scenario and also to expand on the scenario space (see the following sections). Group A contains four different baseline scenarios of growth against the use of a single baseline in the existing energy-economy planning literature, but they are all plausible baselines. Group B contains the corresponding CN scenarios; the aim here is to investigate what it will take for Bhutan to sustain its CN pledge if it pursues those plausible growth pathways defined in Group A.

The scenarios under group A emerge from a macroeconomic outlook and entail a distinct energy system pattern – in terms of type and amount of energy consumed, type of primary resources extracted and type of demand technology used by the demand sectors. Group A comprises the Business-As-Usual (BAU) scenario, the high economic growth (HGDP) scenario, the low economic growth (LGDP) scenario and the Nationally Determined Contributions (NDC) Plan scenario. The NDCPlan scenario attempts to depict some of the key aspects of the NDC committed to by Bhutan, which had outlined nine broad strategies (RGoB, 2015), but without specific targets. This present study has assigned some reasonable quantitative targets for modelling purposes based on past trends and other national level documents, with an intention to reduce carbon emissions.

Group B consists of the CN counterparts for each of the scenarios in Group A, although with a distinct sector in focus (e.g. the 'advanced technology' scenario focuses only on the transport and industry sectors and the 'modern fuel' scenario focuses only on the residential and commercial sectors). Group B is intended to decouple the growing Bhutanese economy and its energy demand from GHG emissions, thereby holding the emission levels within the sink capacity. Decoupling is explained in Newman (2017). In order to formulate Group B scenarios, distinct and exclusive CN measures are specified, as shown in Table 1. Group B scenarios are therefore more challenging to the economy than Group A, but are not seen as highly radical or beyond possibilities.

The various scenarios will be examined to see how they keep within the sink capacity of 6.3 MT (million tons) of CO_2e – this is the total forest sink capacity that can neutralise any carbon emissions produced in Bhutan. Combinations of mitigation measures will also be done to form Group B scenarios.

Group A scenarios

Group A scenarios consist of the BAU, HGDP, LGDP and the NDCPlan scenarios. The BAU scenario represents the 2014 energy-economy trajectory and assumes a GDP growth rate similar to that witnessed over the past two decades (refer to Table 2). Major policy interventions are not anticipated, except for general trends such as the declining usage of fuelwood in the residential and service sectors, due to achievement of nationwide electrification, and some push in the public transport sector. The HGDP scenario represents the high economic growth rate of 10% per annum until 2025 and thereafter sustaining at 7.8%. In recent years, Bhutan has achieved such high growth as a result of commissioning mega-hydropower projects. The LGDP scenario represents a low economic growth of 5.6%, which further declines to 2.5% by 2050. Bhutan has also witnessed such low economic growth in 2012.

Group B scenarios and mitigation measures

For each of the scenarios under Group A, a corresponding CN scenario was formulated based on the selection of mitigation measures outlined below.

This study specified four aggregated measures based on data availability, suitability to Bhutan's context and the emerging global vision, shown in Table 1 with detailed descriptions provided in Appendix (A5.3).

Table 1. Carbon Neutral measures.

CN Measure Groups	*Sector Measures*			
	Residential	*Commercial*	*Transport*	*Industry*
IS (Industrial Symbiosis)	Not Applicable	Not Applicable	Not Applicable	Blended cement (Morrow, Hasanbeigi, Sathaye, & Xu, 2014) and waste heat recovery in other three major industry sub-sectors (NEC & TERI, 2016)
ATECH			Electric vehicles penetration follows the trajectory specified under	Oxy-combustion technology in cement industry from 2045 (ETSAP, 2010);

(Advanced TECHnology)	Not Applicable	Not Applicable	the 2DS of the IEA (2016); LRT is introduced in passenger transportation catering to 30% of the travel demand from 2030	Maerz PFR kiln system in the CaCd industry (Liu et al., 2011);
MF30 (Modern Fuel by 2030)	Traditional bioenergy and kerosene usage in the residential and commercial sectors is reduced to zero (replaced by biogas and electricity) by 2030 following SDG 7 (universal access to modern energy for all)		Not Applicable	Not Applicable
F8050 (80% Fossil fuel reduction by 2050)	Fossil fuel energy demand is reduced by 80% by 2050 as per the target set by IPCC (IPCC, 2014), largely driven by electricity displacing fossil fuels.			

Selection of the mitigation measures

The mitigation measures outlined in Table 1 above were then deployed one by one onto the BAU scenario to obtain the cost of mitigating a tonne of GHG through the cost–benefit summary report in the LEAP model. It was observed that none of the measures, except for F8050, were effective enough on their own to keep the GHG emissions within the sink capacity, despite some of the measures being no-regret options (i.e. options with no cost or negative cost, meaning they save money). Given these limits, the mitigation measures were combined to form groups of cost-effective CN measures to hold the emission level within the sink capacity at the lowest cost of mitigation during the planning period. The process of moving from one combination to the next is based on the cost of mitigation shown in Figure 1. The cheaper options (e.g. first and second lowest) were combined first to see if the emissions level remains within the sink capacity; if not, then the first is combined with the third lowest, and so on. If the combination of any two measures failed to keep the emission levels within the sink capacity, the combination of three measures was applied to the scenario under investigation. This leads to the formation of Group B scenarios.

Figure. 1. The cost of aggregated carbon neutral measures (US$/t$CO_2$e).

Group B – Carbon neutral scenarios

The CNBAU represents the Carbon Neutral BAU scenario, which includes the two mitigation measures 'IS + ATECH' that form the least cost option in holding the emissions level within the sink capacity. Similarly, CN_NDCPlan represents the Carbon Neutral NDCPlan scenario with 'IS + MF30' as the combined measures. The CNHGDP represents the carbon neutral high economic growth (high GDP) scenario with 'IS + MF30 + F8050' as the combined measures. Under the LGDP scenario, the emissions level remains well below the sink capacity, thus application of the mitigation measures does not arise. Low growth may not be an effective policy, however, as economic and social goals are largely pushing the country towards a high growth future based on the need to create opportunities, and growth provides these. Growth is therefore driving the politics inevitably in this direction, as in most emerging countries looking to break out of the poverty cycle. Its implications for energy need to be addressed.

Table 2. The Scenarios – sector conditions and their growth trends.

	Sectors Conditions			
	Residential sector	*Commercial sector*	*Transport sector*	*Industry sector*
BAU conditions	Fuelwood usage in all end-uses expected to decline to 23% by 2050 following the declining rural population; Saturation of households with heating facilities to increase from 50% in 2014 to 70% by 2050.	Fuelwood usage declines by 50%	Bus share increases from 45% to 65% by 2050; Passenger transport by air increases from 20 to 25% by 2050; Light diesel truck share increases from 17% to 30% by 2050.	

NDC Plan conditions *(from the broad strategy outlined in the NDC)*	Fuelwood usage decreases to 10% by 2050; Biogas reaches full potential of 20,000 plants by 2030, which meets 28% of cooking energy demand.	Fuelwood usage decreases to 10% by 2050	Electric vehicles share in the market assumed to follow half of the intake rate specified under 2DS of the IEA (2016).	Improved refractories in cement industry and efficiency improvement in Iron & Steel and Ferro Alloy industries (Morrow et al., 2014); Vocarse kiln system in CaCd Industry (Liu et al., 2011).
Group A Scenarios				
BAU	BAU conditions with GDP growth rate of 7.8% and sustaining at 5.6% until 2050			
HGDP	High GDP growth rate of 10% in 2020 and 2025, thereafter declining to 7.8% by 2050, inherited from BAU			
LGDP	Low GDP growth rate of 5.6% in 2020 and declining to 2.5% by 2050, inherited from BAU			
NDC Plan	NDC conditions with BAU growth rate			
Group B Scenarios				
CNBAU	BAU with CN measures consisting of ATECH and IS			
CNHGDP	HGDP scenario with CN measures consisting of F8050, IS and MF30			
CN_NDC Plan	NDCPlan scenario with CN measures consisting of IS and MF30			

Data Availability. All data generated or analysed during this study are included in this published article (and its supplementary information files).

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Appendix B: Co-Author Statements

Publication 1: Co-Author Statements

Yangka, D., Newman, P., Rauland, V. & Devereux, P. (2018). Sustainability in an emerging nation: The Bhutan case study. *Sustainability, 10*(5), 1622.

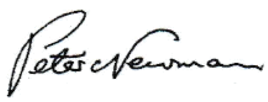
Yangka, D. (60% contribution)
Preparation and completion of manuscript, literature synthesis and conceptualising the 3G model, preparation of figures and tables.

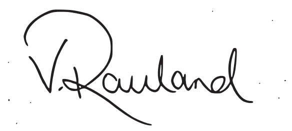
Dorji Yangka, PhD Candidate

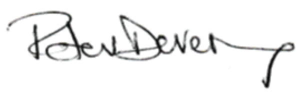
Newman, P. (20% contribution)
Supervising, re-structuring and editing the manuscript; conceptualising the 3G model.

Rauland, V. (10% contribution)
Supervising, revising and editing the manuscript.

Devereux, P. (10% contribution)
Supervising, revising and editing the manuscript.







Professor Peter Newman **Dr Vanessa Rauland** **Dr Peter Devereux**

Publication 2: Co-Author Statements

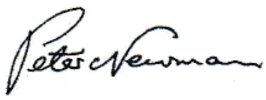
Yangka, D., Rauland, V. & Newman, P. (2018). Carbon neutral policy in action: the case of Bhutan. *Climate Policy*, 1–16.

Yangka, D. (65% contribution)
Conducting the semi-structured interviews, data analysis using NVivo software; Preparation and completion of manuscript, preparation of tables.

Dorji Yangka, PhD Candidate

Newman, P. (10% Contribution)
Supervising and editing the manuscript.

Rauland, V. (25% Contribution)
Supervising, structuring, revising and editing the manuscript.



Professor Peter Newman **Dr Vanessa Rauland**

Publication 3: Co-Author Statements

Yangka, D., Newman, P., (2018). Happiness, environment and wealth: What can Bhutan show us about resolving the nexus? *Modern Economy* (accepted).

Yangka, D. (65% contribution)
Data collection, econometric modelling and regression analysis using EViews software; Preparation and completion of manuscript; preparation of figures and tables.

Dorji Yangka, PhD Candidate

Newman, P. (35% contribution)
Supervising, revising and editing the manuscript.

Professor Peter Newman

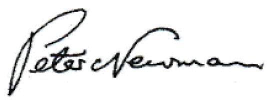
Publication 4: Co-Author Statements

Yangka, D. & Newman, P. (2018). Bhutan: Can the 1.5 °C agenda be integrated with growth in wealth and happiness? *Urban Planning, 3*(2), 94–112. doi: 10.17645/up.v3i2.1250

Yangka, D.   (80% contribution)
Data collection, LEAP modelling and scenario-based analysis of model results; Contextualising Bhutan's case into the 1.5°C agenda; Preparation and completion of manuscript; preparation of figures and tables.

Dorji Yangka, PhD Candidate

Newman, P. (20% contribution)
Supervising, revising and editing the manuscript, in particular linking Bhutan's case into the 1.5°C agenda.



Professor Peter Newman

Publication 5: Co-Author Statements

Yangka, D., Rauland, V. & Newman, P., (2018). Carbon neutral Bhutan: Sustaining carbon neutral under growth pressures (submitted).

Yangka, D. (60% contribution)
Data collection, LEAP modelling and scenario-based analysis of model results; preparation and completion of manuscript; preparation of figures and tables.

Dorji Yangka, PhD Candidate

Newman, P. (25% contribution)
Supervising, revising and editing the manuscript; re-structuring of introduction and background sections.

Rauland, V. (15% contribution)
Supervising, revising and editing the manuscript from the first draft.

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