



The value of lost output and cost of illness of noncommunicable diseases in the Pacific



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ABSTRACT

Background and Objectives: The Pacific Island Countries face some of the highest rates of Noncommunicable Diseases (NCDs). This study estimates the economic costs of NCDs for each year from 2015 to 2040, focusing on eleven Pacific Island nations.

Data and Methods:

Two methods were used to estimate the mortality and morbidity costs using a ‘value of lost output’ and ‘cost of illness’ approach respectively.

Results: Five results stand out in terms of projected economic costs of NCD mortality and morbidity analyses in the Pacific: (i) The economic burden of NCDs in the Pacific is greater than expected for middle-income countries; (ii) Although cardiovascular disease is the biggest contributor to the mortality burden in the region, diabetes plays a far greater role in the Pacific countries compared to the global average; (iii) The economic burden of NCDs is increasing with time, especially as incomes rise; (iv) The biggest driver of lost output is the potential loss of labor due to early death from NCDs; and (v) The cost of illness due to diabetes is high across the Pacific countries, with highest among the Polynesian countries.

Conclusions: NCDs alone can put enormous threat to the small Pacific economies. Targeted interventions to reduce disease prevalence, as outlined in the Pacific NCDs Roadmap, are vital to reduce the long-term costs associated with NCD mortality and morbidity.

1. Introduction

The Pacific Island Countries (PICs) face some of the highest rates of Noncommunicable Diseases (NCDs), as well as risk factors for developing NCDs such as obesity and tobacco consumption in the world [1]. However, there is only limited published research on the impact of NCDs on Pacific economies, with most of the economic related NCD research focusing on the impact on government health budgets [2]. There is little hard data, and virtually no peer reviewed literature, on the broader economic impacts including the effects of premature death, absenteeism, and disability on workforce participation, or savings and investment. This paper estimates the economic costs of NCDs using a “value of lost output” approach for NCDs mortality and a “cost of illness” approach for diabetes morbidity to 2040. Due to data limitations, we were not able to extend the cost of illness methods to all NCDs as desired. While the methods are not all encompassing of the

total economic burden that NCDs pose, they provide a lower bound estimate of the severity of the problem that the Pacific nations face.

2. Background

The Prime Ministers and leaders of the 14 countries making up the Pacific Island Forum have declared the Pacific to be facing an “NCDs Crisis”. Like many other middle-income countries, NCDs are now the leading cause of death in most countries in the Pacific, ranging from an estimated 60 % of deaths in Solomon Islands to 77 % of deaths in Fiji [3]. NCDs are also an important driver of premature (< age 70 years) deaths in most of the Pacific Nations, with rates measurably higher than lower-middle-income global averages. However, what makes the PICs unique is the disproportionately high level of certain NCDs by global standards. According to the International Diabetes Federation Diabetes Atlas 7th edition, the Pacific contains seven of the top ten diabetes-prevalent countries in the world [4].

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The percent of people affected by NCDs will rise substantially in the Pacific in the coming decades. This projected increase is driven by at least two forces. The first force is the interaction between two major demographic trends: high population growth and aging. Most Pacific countries have relatively high total fertility rates and low contraceptive prevalence rates compared to other middle-income countries. While the total number of population increase will not directly increase the prevalence rate of the NCDs, the share of those aged 60 and older has begun to increase and is expected to grow very rapidly in the coming years[5]. Since NCDs disproportionately affect this older age group, the incidence of these diseases can be expected to accelerate in the future.

The second force driving the escalating NCDs rate is the high level of risk factors prevalent in the Pacific. Behavioral risk factors, including obesity, tobacco use, physical inactivity, and unhealthy diet, are important proximate causes of NCDs in the Pacific. Fig. 1 presents the NCDs death rates attributable to behavioral risk factors of individuals for nine countries. Tuvalu and Palau were excluded due to lack of available data. The results were aggregated across both genders and all ages. Dietary risk (e.g. diet high in sweetened beverages, diet high in *trans*-fat, diet high in sodium etc.) is the greatest risk factor for cardiovascular diseases induced deaths in the Pacific. Dietary risk factors also constitute the highest behavioral risk factors for death due to diabetes. Low physical activity imposes significant risk of death caused by cardiovascular diseases, diabetes, and cancer.

Obesity is an important risk factor for NCDs including diabetes, cardiovascular disease and cancer [6]. WHO estimates that the top ten countries with highest obesity rates in the world are in the Pacific [7]. Over 50 % of adult women are obese in eight countries, and one third or more of women are obese in 14 countries of the Pacific

for which data is available [8]. Over one-fourth of the adult population in most PICs is clinically obese [9].

Tobacco use is also an important risk factor. WHO notes that “tobacco is the leading behavioral risk factor causing substantially large number of potentially preventable deaths worldwide, one death every-six seconds” [10]. Tobacco users lose at least one decade of life expectancy compared to those who never smoked [11]. Prevalence of tobacco consumption in the Pacific is much higher than the global average of 21 % [3]. In 2012, adult males in Kiribati and PNG had the 3rd and 5th highest rates of smoking in the world with prevalence rates of 67 % and 55 % respectively [12]. Tobacco consumption among males in Tonga, Solomon Islands, and Vanuatu is also quite high; 43 %, 45 %, and 43 % respectively [3].

Other trends and risk factors also point to a substantial worsening of the situation. More than 70 % of women have insufficient physical activity in FSM and Marshall Islands; and over 30 % of adult men and women in Vanuatu suffer hypertension [3]. While rates of physical inactivity and alcohol consumption have decreased in both Samoa and Tonga over the last ten years, rates of obesity have barely changed in Tonga and have increased in Samoa [3].

PICs face a significant health financing challenge. Most countries in the Pacific have a larger share of public expenditure allocated to health as a percentage of GDP than the global average for upper middle-income and lower middle-income countries [13,14]. Public expenditure on health including external grants constitutes a large part of total health expenditure [15]. However, the Pacific faces historically low, or in some cases volatile rates of real GDP per capita growth [13,14,16]. The rates of government tax revenue as a percentage of GDP are generally low and countries have high vulnerability to external economic shocks and natural disasters [17]. All these factors raise the question as

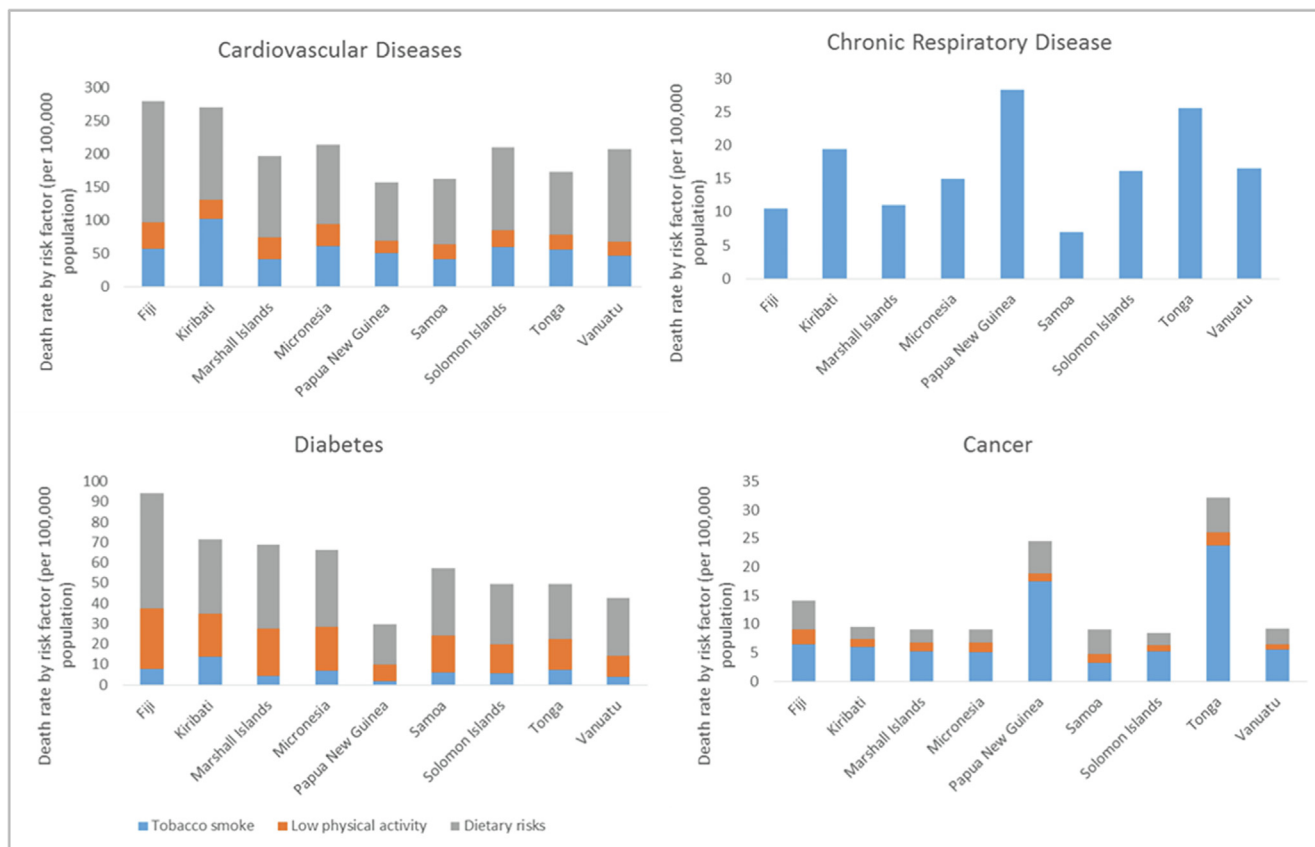


Fig. 1. NCD Mortality Rates Attributable to Behavioral Risk Factors. Source: Institute for Health Metrics and Evaluation (IHME).

to whether the expansion of public health expenditure as a share of the economy is financially sustainable [2].

The global evidence increasingly shows that NCDs result in long-term macroeconomic impacts on labor supply, capital accumulation, and GDP growth [18–23]. NCDs directly affect the quantity of the labor force through premature death of workers, or disability as the result of stroke or diabetic-related blindness and amputation. NCDs also affect the quality of the labor force through a variety of channels including absenteeism, co-morbidity including mental health issues and disability. Premature death and disability caused by NCDs can also have indirect and longer-term effects as well. If young children are taken out of school to look after a relative with diabetic blindness, then the possibility for the next generation to improve their own living standards is compromised. There are particularly adverse long-term social effects if young girls are taken out of school to look after sick relatives [24].

Pacific Island Leaders formally declared in 2011 that NCDs in the Pacific have become “a human, social, and economic crisis”. Pacific Island Prime Ministers and other Leaders furthermore “expressed alarm that 75 % of all adult deaths in the Pacific are due to NCDs, the majority of whom are in the economically active age bracket and that many more times this number suffer severe side effects that undermine their capacity to contribute further to economic development” [25].

3. Data source and methods

This study estimates the economic costs of NCDs for each year over the 2015–2040 period, focusing on the Pacific Island nations: Fiji, Kiribati, Marshall Islands, Micronesia (F.S.M), Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, and Vanuatu. Two methods were used to estimate the mortality and morbidity costs using a “value of lost output” and “cost of illness” approach respectively. While the methods are not all encompassing of the total economic burden that NCDs pose, they provide a lower bound estimate of the severity of the problem that the Pacific nations face.

3.1. Data source

The analysis uses various secondary data sources for estimations, including data from the International Labor Organization (ILO), World Health Organization (WHO) Global Burden of Disease and International Diabetes Federation (IDF).

More specifically, the following data sources were used for the mortality burden analysis: labor force projections 2005–2040 from ILO [26]; disease-specific mortality projections, country macro parameters, and population projections were provided by the WHO Global Burden of Disease Estimates 2005–2040 [27]; and GDP per capita estimates were sourced from World Bank staff estimation [28].

The prevalence of age-standardized adjusted diabetes projections comes from the Global Status Report on Noncommunicable Diseases 2014, which provided the prevalence rate of raised blood glucose for 18 years of age and older in the year 2014 [29]. From the International Diabetes Federation’s (IDF) projected diabetes prevalence rates for 2015 and 2040, a constant growth rate in diabetes prevalence was calculated for years 2015 through to 2040 and applied to the Global Status report figures. The constant growth rate may not be the most accurate way in estimating annual diabetes case growth rate, some other literature also used linear constant growth in diabetes prevalence increase [30]. Estimated medical costs per diabetic were also sourced from IDF [4]. GDP per employed uses employment and GDP data, which are sourced from World Bank staff estimation [28].

3.2. Value of lost output (Mortality Burden)

The economic burden of NCDs mortality in the Pacific countries was estimated using the WHO EPIC model which takes a “value of lost

output” approach to disease mortality burden [18,31,32]. This tool estimates country-specific economic output (GDP in 2010 US\$) using a standard growth model that relates aggregate output to capital and labor inputs, augmented by technology. NCDs mortality enters the model with a twofold effect on aggregate output: first, NCD mortality depletes the labor force, and second, capital accumulation is impeded as savings are diverted to NCD associated healthcare consumption.

The economic burden of NCDs is estimated by taking the difference between the status quo (SQ) projections of country output, also known as the “business-as-usual” output, and the counterfactual scenario output, described as the projected output had there been no NCD mortality cases.

The WHO EPIC model assumes no one under the age of 15 is in the labor force. We estimated 2030 economic burden in order to compare with the global average and the average of middle-income countries. 2040 economic burden due to mortality is also estimated in order to give the magnitude of problem if the NCD epidemic is not controlled.

3.3. Cost of illness (Morbidity Burden)

The morbidity burden is estimated using a cost-of-illness approach [33], restricting the initial analysis to diabetes due to data limitations. There are not reliable secondary data available to forecast the incidence and prevalence rates for NCDs other than diabetes. For diabetes, we used the International Diabetes Federation’s diabetes prevalence rates for 2015 and 2040 and estimated a constant growth rate in order to give projections for 2015 through to 2040 [4]. The growth rates were estimated ranging from 0.99 % to 3.13 % yearly, dependent on the country. Loss of income and medical costs are estimated following the Bloom et al. report [31]. The disability prevalence among low- and middle-income countries is estimated to be 8 % [34]. This percentage was also adopted by the World Economic Forum [35]. Medical costs are applied to diabetics 15 years of age and over while the loss of income and tax loss are only accounted for 20 to 65 years old. While most PIC countries have a retirement age less than 65 years old, most PICs have a large section of informal sector [36]. We use the income loss counting individuals age from 20 to 65 as they may still contribute to the economy (such as in the agriculture or fishery industries) after the mandatory retirement age. The method also assumes that an individual driven to early retirements from diabetes does so at the beginning of the year.

The medical care costs associated with diabetes is drawn from IDF Diabetes Atlas 7th Edition [4] which provides healthcare expenditure by country for the years 2015 and 2040. A constant growth rate between the two years provides the medical cost associated with all other years of analysis. The loss in tax revenue is calculated as that year’s tax that would have been paid had the individual not been removed from the workforce due to diabetes. The loss in tax revenue is calculated at the average income level tax rate by countries [37]. One strong assumption is constant country-specific tax rate across all years.

Taking the human capital approach to estimating the productivity costs of disability, the value of lost income is estimated using the value of GDP per employed multiplied by the disability prevalence. The economic cost is the difference in income between employment and unemployment. The summation of these economic burdens gives the lower bound estimate of total economic burden due to diabetes morbidity.

4. Results

4.1. NCD mortality burden

A key finding reveals the NCD mortality burden is much greater in the Pacific Island countries than global standards. The estimated effect

of four major types of NCDs (cardiovascular diseases, chronic respiratory diseases, diabetes, and cancer) on the global economy is approximately 3.25 % of the 2010 global GDP (Table 1). The projected 2030 economic burden for eight of the Pacific countries analyzed (PNG, Vanuatu, Tonga, Fiji, Marshall Islands, Micronesia, Palau, and Tuvalu) is significantly higher than the middle-income average burden. Kiribati, Samoa, and Solomon Islands are near to the middle-income average burden in 2030.

The economic burden is estimated to escalate even further from 2030 to 2040. That is because a premature death due to NCDs has a long-term impact on the economy through the loss of the deceased’s potential productivity in the workforce. If no action is taken, the economic burden of NCD mortality is projected to increase significantly.

Cardiovascular disease accounts for the greatest mortality burden in the Pacific Islands, followed by diabetes. The disease mortality burden breakdown is presented in Fig. 2. Cardiovascular disease is projected to account for 43 % of lost economic output in the 11 Pacific countries, diabetes contributes at nearly-one quarter (24 %) of lost economic output on average. Of the 11 countries analyzed, in 2040, Fiji will suffer the highest cardiovascular burden at roughly 60 %. In 2040, Vanuatu will suffer the highest diabetes burden at roughly 38 %, even higher than the burden from cardiovascular disease.

The biggest driver of lost output is the potential lost labor due to early death from NCDs. Table 2 illustrates the potential loss of effective workers due to NCDs by the year 2040. In 2040, NCD mortalities will potentially reduce the labor force by 9 % to 30 % across the 11 countries. Again, cardiovascular disease will have the greatest impact, causing an especially high amount of lost labor in Fiji and Micronesia. Diabetes is especially severe in Vanuatu, which has almost doubled the lost effective labor force compared with other Pacific countries.

4.2. Diabetes morbidity burden

The estimation of NCD morbidity economic costs is more complicated than NCD mortality costs. When an individual die prematurely from an NCD, that person ceases any further contribution to economic activity and no additional medical costs are incurred. However, in the case of NCD morbidity, individuals can continue partially or fully contributing to productive activities. Their contribution is difficult to estimate in advance. However, they also continue to require medical treatment including drug costs and forgone health worker time. Again, those costs will vary a great deal according to the severity of the disease.

The morbidity burden is estimated using a cost-of-illness approach, restricting the initial analysis to diabetes due to data limitations. More specifically, the projection of prevalence of other NCDs are not readily available in the international database. Three major areas contribute to the cost of diabetes are medical costs, loss of income, and loss of

Table 1
Economic Burden of NCDs due to Mortality as a Proportion of GDP, 2030 and 2040.

	2030	2040
Fiji	6.83 %	10.94 %
Kiribati	6.52 %	9.23 %
Marshall Islands	10.04 %	13.61 %
Federated States of Micronesia	8.30 %	12.93 %
Palau	8.73 %	12.75 %
Papua New Guinea	9.12 %	15.13 %
Samoa	5.60 %	8.49 %
Solomon Islands	4.91 %	8.63 %
Tonga	8.32 %	12.30 %
Tuvalu	10.50 %	14.86 %
Vanuatu	8.37 %	14.31 %
Global Average	3.25 %	
Middle Income Country Average	5.22 %	

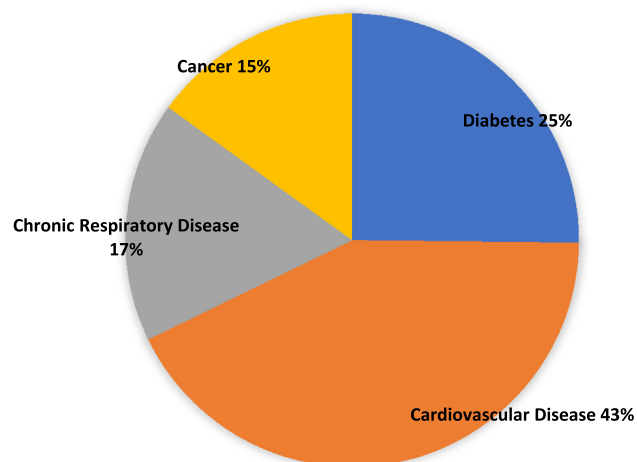


Fig. 2. Average Share of the Lost Economic Output by NCDs in the Pacific Countries, 2040.

tax revenue. The estimated cost of diabetes ranged between 2.5 % and 7.4 % of country-specific GDP in 2015 (Fig. 3). The data is organized by the three major geographic areas in the Pacific: Melanesia, Polynesia, and Micronesia. The costs are expected to grow, reaching levels of 4 % to almost 12 % by 2040, with the biggest share attributable to loss of income.

The cost of illness due to diabetes is highest among Polynesian countries, particularly in Tuvalu. Melanesian countries are currently experiencing a lower cost of illness burden due to diabetes, but the burden is projected to rise quickly. The cost of diabetes is already quite high in most Micronesian countries and will continue to rise.

Melanesian countries face a double burden of diseases, with the combination of NCDs and an “unfinished agenda” of reducing communicable diseases, maternal and newborn mortality; Some Pacific countries are still struggling with high prevalence of under-nutrition among children [38]. The prevalence of NCDs is rapidly increasing, particularly in urban areas. This burden will be likely further compounded by the high stunting rates for children under five, particularly in Papua New Guinea [38]. Research has shown that stunted children are more prone to developing NCDs in adulthood [39]. The steep slope of the burden curve, over the analysis time period, indicates the severity of the problem if no action is taken to reduce diabetes morbidity.

5. Limitations

There are several caveats that this study needs to acknowledge.

This study does not consider the distribution of NCDs across income levels. It is well known that disease is not impartial and that the less educated are encumbered by more than their equal share of the disease burden [40]. The less educated tend to earn lower wages while the assumption states that an individual cured of a disease would on average earn the expected wage of an economy. Therefore, the estimated loss of output may be overestimated.

Secondly, the costs associated with diabetes morbidity are not all encompassing. Among the costs not calculated in this study are the loss of income (and productivity) for those who are withdrawn from the labor force to look after diabetic family members. Temporary disability, as in the case where a diabetic is withdrawn from the workforce for a short period, is not counted. The PICs are known to receive a high number of remittances [41]. The lack of inclusion for this form of income may cause underestimation in the lost income estimates. However, the households with diabetics receiving remittances may use this income to ease the burden of diabetes, for example, to supplement the

Table 2
Percentage of Lost Effective Labor Force in the Year 2040 due to NCDs.

Country	Diabetes	Cardiovascular Disease	Chronic Respiratory Disease	Cancer	Total
Fiji	3.7	10.0	1.2	1.5	16.4
Kiribati	3.5	3.6	0.8	3.0	10.8
Marshall Islands	3.5	7.2	2.3	3.1	16.2
Micronesia	8.6	11.3	8.2	1.8	29.9
Palau	3.1	5.7	2.5	2.4	13.8
Papua New Guinea	2.7	7.2	3.1	1.8	14.7
Samoa	1.7	5.6	2.8	2.4	12.4
Solomon Islands	2.4	3.8	2.3	1.0	9.4
Tonga	3.8	7.1	3.7	3.9	18.5
Tuvalu	3.7	7.1	2.6	3.2	16.6
Vanuatu	7.1	5.7	3.1	3.1	18.9

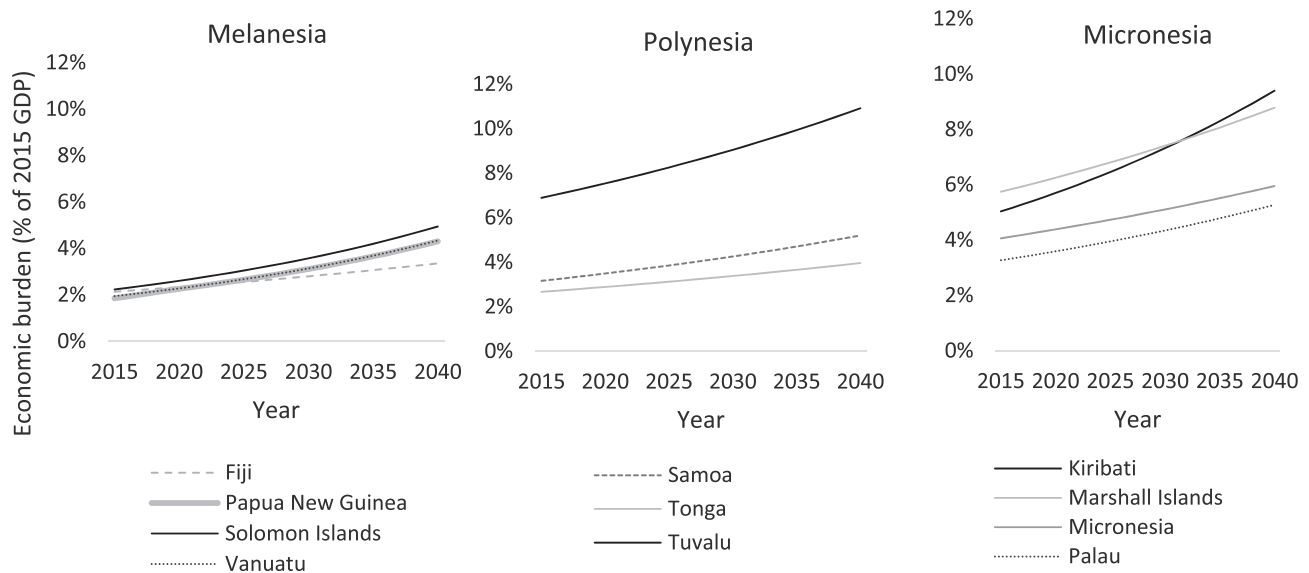


Fig. 3. The Economic Burden of Diabetes Morbidity as a Proportion of Country Specific GDP, 2015.

family members caring for the ill. These remittances, used to ease financial burden associated with disease, can then be considered as an indirect cost of morbidity. The degree to which this in the case, however, is difficult to determine.

Thirdly, significant data limitations need to be acknowledged. The specific information for each country on NCD morbidity data in terms of prevalence, incidence, disability rates are limited, which are main reasons that we only use the cost of illness approach for diabetes. Our analysis uses several secondary data, including data from WHO and IDF so carries the data limitations from these secondary data sources. Data on NCDs are generally very thin in the Pacific region. IDF is the best data source that we can obtain for diabetes for the Pacific countries while conducting this analysis. They are far from being perfect. Therefore, more frequent surveillance, such as World Health Organization WHO STEPwise Approach to NCD Risk Factor Surveillance (STEPS) can be valuable in building stronger empirical evidence.

Fourthly, this paper uses the original formulation of the EPIC model, which relies on Solow framework and was designed by the World Health Organization. More recent literature [42,43] proposes a novel framework that builds upon the WHO EPIC model and considers (i) heterogeneous human capital levels of workers in different age groups, (ii) the NCDs and health conditions not only lead to mortality but also morbidity, and (iii) the effects of treatment costs on capital accumulation. This paper considers the latter two elements through the cost of illness model but did not include the heterogeneous human capital levels of workers in different age groups.

Lastly, our analysis relies on the modelled estimates to reference years. The process relies on important assumptions. Sensitive analysis

was conducted through the process. Though the overall trends and key messages stay the same, the specific numbers should be used with caution.

6. Discussions

Reduction of the NCDs burden is a global development imperative to achieve the Sustainable Development Goals (SDGs), including the target 3.4 to reduce premature NCD mortality by a third by 2030 [44]. PICs have some of the highest rates of NCDs and risk factors for NCDs [3]. This paper projects the economic costs of NCDs in these countries using lost output and cost of illness approaches. We highlight five important findings. First, comparing to the global average, the economic costs of NCDs due to mortality burden is much greater in the PICs, implying the potential devastating effects of NCDs on the small economy. Second, cardiovascular disease accounts for the greatest economic burden in the Pacific, followed by diabetes. Third, the economic burden of NCDs is increasing with time, especially as income rises; Fourth, the biggest driver of lost output is the potential loss of labor due to early death from NCDs. Fifth, the cost of illness due to diabetes is high across the Pacific countries, with highest among the Polynesian countries.

Pacific economy is small and volatile [45]. NCDs impose large direct and indirect costs to the Pacific nation and can put enormous threat to the Pacific economies. Pacific island leaders have recognized the problem and declared that the Pacific region was facing a “human,

social and economic crisis” from NCDs at the 42nd Pacific Islands Forum in 2011.

However, most NCDs are preventable, or at least can be postponed with proven, often affordable, and cost-effective interventions [46]. It therefore makes sense on economic grounds to invest resources to reduce the impact of NCDs. The more difficult issue is then to decide the appropriate level of resources to invest in responding to NCDs given other competing demands inside and outside the health sector; where and how resources can be mobilized in ways that are efficient and sustainable; and where scarce resources should be allocated.

In recognition that NCDs are largely preventable, the Pacific leaders tasked Pacific development partners to work with countries to prepare an *NCD Roadmap Report* [1] with analysis and NCD response options for the Pacific region and individual countries within the region. The analysis and recommendations in the *NCD Roadmap Report* were based on the best available international evidence for effective, feasible, and “best buy” strategies, as well as widespread consultation among key stakeholders including PICs and their development partners. The *NCD Roadmap Report* was then presented to a Joint Forum Economic and Pacific Health Ministers’ Meeting in the Solomon Islands in July 2014 and endorsed by the Pacific leaders.

They also jointly agreed to the following five strategic action areas [47]:

i. Strengthen tobacco control by an incremental increase in excise duties to 70 percent of the retail price of cigarettes over the medium term;

ii. Consider a tax increase for alcohol products as a way of reducing harmful alcohol consumption;

iii. Consider policies such as targeted preventative measures, taxes, and better regulation to reduce consumption of local and imported food and drink products that are high in sugar, salt, and fat content as they are directly linked to obesity, diabetes, heart disease, and other NCDs in the Pacific;

iv. Improve the efficiency and impact of the existing health budget by reallocating scarce health resources to targeted primary and secondary prevention measures for cardiovascular disease and diabetes, including through the Package of Essential Noncommunicable Disease Interventions; and

v. Strengthen the evidence base to enable better investment planning and programme effectiveness, thereby ensuring that interventions work as intended and provide value for money.

Translation from the NCD Roadmap recommendations and actions is a challenge, but some reasonable progress has been made. Most countries covered in this paper have increased taxes on tobacco or are in the process of doing so. However, understanding the impact of tobacco tax increase on various fronts are still limited. Tonga, Samoa, and Vanuatu all increased the tax on sugar-sweetened drinks. There are also ongoing efforts to introduce food safety regulations requiring nutrition labels on processed foods. The Cook Islands, Fiji, FSM, Kiribati, Nauru, Niue, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu and Vanuatu have all commenced implementing the WHO supported *Package of Essential NCD (PEN) Interventions for Primary Health Care in Low Resource Settings* [48]. When used judiciously and adapted to each country’s disease burden, risk factors, cost structures, and health system capacities, such an approach should identify and deliver the “best buys” for diagnosing and treating NCDs.

However, implementation is still lagging. It is quite common for good policies to be developed and laws enacted in developing countries, only to find that actual implementation is neglected or not given adequate resources and attention [49]. In the short term allocating the necessary funds remains as a challenge, especially for the many low- and middle-income countries in the region that are facing a steep increase in the prevalence and incidences of NCDs. Technical assistances are also required from international development community to formulate and implement more evidence based policies[50].

7. Conclusion

Moving forward, the Pacific countries need to urgently control the epidemic growth of NCDs and avert some of the broader economic costs to achieve sustainable growth. The paper, by quantifying the magnitude of economic burdens of NCDs in the Pacific countries, hopes to better inform the national and international health community the urgency of action to react to the formidable economic threats posted by NCDs in the Pacific Island Countries.

CRedit authorship contribution statement

Xiaohui Hou: Conceptualization, Methodology, Supervision, Writing – original draft. **Ian Anderson:** Conceptualization, Validation, Writing – original draft. **Ethan-John Burton-Mckenzie:** Software, Validation, Data curation, Visualization, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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