Human Development Index: PNG progress optimization model

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Abstract

Human Development Index (HDI) is a holistic measure of human well-being, which is essential for a nation’s strategic development plan. This paper aims to identify Papua New Guinea’s (PNG’s) government planning policies that improve the indicators of the PNG HDI and propose modifications to the indices to model the achievement of the PNG Vision 2050 goals. Modifying the indices would help refine policies that could enhance PNG to be ranked among the top 50 countries in the United Nations Development Program’s Report. Currently, PNG HDI is ranked at 0.555 and is categorized as a medium human development country. Using an optimization model on current PNG HDI data through an objective function, a maximized ranking for PNG is generated. The objective function is solved through linear programming with a maximized value between 0.7 to 0.9, thus placing PNG amongst the top high human development countries and thereby achieving its’ 2050 goal.

Keywords: Human development index, education index, health index, income index, optimization model, linear programming, data envelopment analysis.

Introduction

Every year, the United Nations Development Program (UNDP) publishes a report based on a country’s Human Development Index (HDI) ranking. The HDI rank is simply a composite measure between 0 and 1 quantifying human well-being in terms of a country’s education, health and income indices per annum.

Mariano et al. (2021) showed researchers to employ the use of the Data Envelopment Analysis (DEA) approach to further explore the human development index. It is a technique based on linear programming for determining the efficiency of decision-making in transforming a set of inputs into a set of outputs (Mariano et al,2021). Yekta et. al. (2018) describes DEA as a powerful mathematical programming method that measures the relative performance of a country in terms of human development and is defined based on the data given in the Human Development Reports that is published annually by UNDP (Despotis, 2001). A simplified index maximizing linear programming model is used to estimate an ideal value of the composite index for PNG with reference to neighbouring countries in the high human development group namely, Hong Kong, Singapore and Australia. The present values of the indicators (Table 2) giving the level of education attainment (EI), long years of living healthily (HI) and standard of living (II) reflects the current governing policies on a national scale. These values can be increased in the next 30 years (2020-2050) in accordance with the PNG Vision 2050 seven strategic focus areas. To minimize the high illiteracy and poverty rates, the nation focuses all its efforts on increasing the education index by promotion of human capital development, gender, youth and people empowerment. In doing so, it strives to achieve the key outcome of changing and rehabilitating the mindset of all citizens (PNG Vision 2050). Even so, one of the economic growth projections involves increased downstream processing. The earnings from this will contribute to increasing the income index, where the economy is proposed to grow in real terms at an average of 4.5 per cent per year up to 2020 (PNG Vision 2050) increasing income per capita. Unfortunately, this is not true by computations according to GNI per capita data from Table 1. Hence, this paper analyses the current data available for PNG HDI through an ideal optimization model, which could be used to improve government policies that would improve each HDI indicator. The main constraints from the factors affecting the PNG HDI are illiteracy and poverty rates, challenging geographical terrains for important government services, Covid-19 restrictions and high infrastructure costs.

The results obtained from the DEA approach optimization model is important for PNG government planners to keep track of its 50 years' strategic development plan. A planner can check if the goals are achieved or not within a minimum of 5-10 years so changes can be made accordingly until the 2050 goals are achieved.

Literature review

Engineer et.al (2008) proposed the HDI as a criterion for optimal planning. The best optimal solutions obtained from the linear model that represents the composite indices of a planners' problem is the way forward for better and improved government policies for a nation's development. Such a model is necessary for implementation in PNG, where growth and development are paramount. A critical issue pointed out when estimating the HDI is that equal weights are assumed for its three component indices (Despotis, 2005). To address this issue, the DEA approach was used to assess the relative performance of a country's human development based on the data given in the Human Development Report annually by the UNDP. Mariano et.al (2021) further outlined the advantages, disadvantages and possibilities of applying different approaches to DEA in human development indicators. Hence, a simplified index optimization model is proposed for PNG in this paper. The PNG government has documented a 40-years strategic development plan through its National Executive Council which was documented and launched in 2009 (Papua New Guinea Vision 2050). A thorough analysis was done to check whether the PNG government was able to reach some of its strategic goals for 10-years up to 2020 as outlined in the PNG Vision 2050 booklet. The strategic focus areas that underpin the vision 2050 includes human capital development and wealth creation apart from the other five pillars. Current government policies need updating specifically on human capital development and wealth creation for increment in the current PNG HDI rank to achieve the vision "to be among the top 50 countries in the United Nations Human Development Index" (PNG Vision 2050, pp.13-14).

Current practices, challenges and problems

The PNG Vision 2050 strategic plan is divided into a 20-year plan called the PNG Development Strategic Plan 2010-2030 (PNG DSP 2010-2030) whose goal is for the country to attain the middle-income status by 2030. The PNG DSP 2010-2030 mentions using the PNG Government's computerized general equilibrium model (PNGGEM) where appropriate to quantify the goals and scenarios. The problematic issue with this method is that equilibrium models are based on economics and have no correspondence to formal mathematical model concepts.

As discussed by Ambang (2019), the main challenge is measuring the progress of the strategies in place, which has an impact on the country as a whole. The country's ranking has been moving at snail-pace towards the overall goal as shown in Figure 1 below by the green line. This poses the question of whether or not PNG will achieve its set goals by 2050. The problem lies with authorities not being able to track the progress of planned development and policies that governs proper development. The sooner this is addressed, the higher the chances of acquiring the set goals. This paper shows a mathematical proven outcome of areas needing improvements if we are to reach the goal within the set time frame. The current HDI is 0.555 and ranks 155 out of 189 countries sitting in the medium human development group (UNDP 2020b). To reach the goal of ranking in the top 50s, the HDI has to be equal to or greater than 0.7 to qualify for high human development (UNDP HDI Report, 2020).

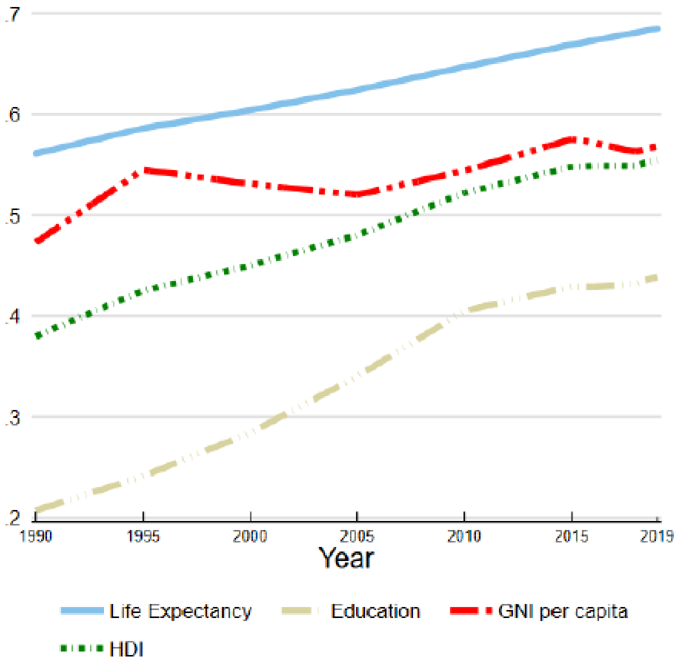

Figure 1: Trend's in Papua New Guinea's HDI component indices 1990-2019.
Source: UNDP HDI Report (2020)

Method

The first step involves computation and tabulation of current PNG HDI data in its raw form extracted from the UNDP PNG Human Development Report 2020. The raw data is then tabulated into its normalized form using the rules of HDI computation as stated by Gebo & Anderson (2019). The HDI, a composite statistic, that measures human well-being using three indices are calculated as follow;

1. Life Expectancy Index (LEI) $= \frac{LE-20}{85-20}$,

where LEI is 1 when Life Expectancy at birth is 85 and 0 when Life Expectancy at birth is 20,

2. Education Index (EI) $= \frac{MYSI+EYSI}{2}$,

   where;

   i) Mean Years of Schooling Index (MYSI) $= \frac{MYSI}{15}$ given that fifteen is the projected maximum of this indicator for 2025

   ii) Expected Years of Schooling Index (EYSI) $= \frac{EYS}{18}$ given that eighteen is equivalent to attaining a master's degree in most countries,

3. Income Index (II) $= \frac{\ln(GNIpc)-\ln(100)}{\ln(75{,}000)-\ln(100)}$,

   where II is 1 when GNI per capita is $75,000 and 0 when GNI per capita is $100.

4. The geometric mean of the three indices above is the calculated HDI, thus

   $HDI = \sqrt[3]{LEI.EDI.II}.$

In the second step, a model is developed as a government planner's problem with concepts derived from the DEA approach by (Despotis,2005) and a static closed economy model (Engineer et.al, 2008). In the next step, the planner's problem is solved through linear programming followed by results and discussions. Finally, a conclusion about the results is made.

HDI data normalization

HDI indicators with raw data extracted from the UNDP PNG Report 2020 is shown in table 1 for the years 1990-2019.

Table 1: Papua New Guinea's HDI trends based on consistent time series data and new goalposts. Source: UNDP Report (2020)

	Life expectancy at birth	Expected years of schooling	Mean years of schooling	GNI per capita (2017 PPP$)	HDI value
1990	56.5	4.7	2.3	2,289	0.380
1995	58.1	5.2	2.9	3,682	0.425
2000	59.3	6.3	3.3	3,368	0.450
2005	60.5	8.0	3.6	3,126	0.480
2010	62.0	9.8	4.0	3,661	0.522
2015	63.5	10.2	4.3	4,512	0.548
2016	63.7	9.9	4.6	4,414	0.549
2017	64.0	10.0	4.6	4,267	0.549
2018	64.3	10.0	4.6	4,152	0.549
2019	64.5	10.2	4.7	4,301	0.555

Observe from Table 1 that life expectancy at birth for Papua New Guineans has an increment value of 3 after every decade from 1990-2020. Expected years of schooling increased slowly from 4 to 10 by an increment of only 6 years within 3 decades with mean years of schooling currently at 4.7. Income earned by the country each year since 1990 grew at a slow pace with an increment of only $2000 from $2,000 to $4000**.** PNG was not able to generate much income since 1990. These observations are important for determining the measure of human well-being as reported in UNDPR for PNG in 2020 (PNG UNDP HDR,2020).

The raw data extracted from Table 1 are used to normalize the HDI data to obtain the current HDI for PNG at 0.555. This is computed in Table 2 using the geometric mean of health, education and income indices by substituting 2019 HDI data provided in Table 1 into the formula $HDI = \sqrt[3]{HI.EI.II}$.

Table 2: HDI data normalization on PNG HDI Data (2019)**.** Source: UNDP(2020b)

Sub-indicator	Formula	PNG Data(2019)
Health Index (HI)	$H = \frac{LEI - 20}{85 - 20}$	$H = \frac{64.5 - 20}{85 - 20} = \frac{44.5}{65} = 0.68462$
Education Index (EI)	$E = \frac{MYS/15 + EYS/18}{2}$	$E = \frac{4.7/15 + 10.2/18}{2} = 0.44$
Income Index (II)	$I = \frac{\ln(GNIpc) - \ln(100)}{\ln(75000) - \ln(100)}$	$I = \frac{\ln(4301) - \ln(100)}{\ln(75000) - \ln(100)} = 0.56819$
Human Development Index	$HDI = \sqrt[3]{HI.EI.II}$	$HDI = \sqrt[3]{(0.68462).(0.44).(0.56819)}$= **0.55522**

Notice that the same formulation from Table 2 can be used for computing the HDI for future years when data becomes available. For the years 2020 through to 2050, the PNG Government is aspiring for economic growth at some desirable rates underpinned by key development projects including better service delivery, improved education by promotion of human capital development, improved health services and sound political leadership and structures (PNG Vision 2050). We can observe the reality of this statement through an optimal solution of the model nesting the HDI of PNG with great emphasis on the educational attainment of the nation’s entire population.

Based on the trends observed from the statistics in Table 1, the following predictions can be made for the remaining 3 decades leading up to 2050. First, life expectancy at birth has a growth rate of 3 years per decade. Expected years of schooling has grown by 2-3 years per decade. Mean years of schooling has a slow growth rate of 1 per decade. Finally, we have the gross national income per capita at a low growth rate. We formalise this in table 3 and make fair predictions for the future, which may affect the HDI to rise to the top 50 human development group.

Table 3: Predicted normalization HDI data for 2020-2050

Year	Life expectancy at birth	Expected years of schooling	Mean years of schooling	GNI per capita($)	HDI value
2020	65	10.5	4.9	4,500	0.566
2030	68	12.5	5.9	6,500	0.615
2040	71	14.5	6.9	8,500	0.689
2050	74	16.5	7.9	10,500	0.771

The model

We follow the DEA-like approach where component indices contribute positively to the HDI. Despotis (2005) suggest an output-oriented DEA model by assuming constant return-to-scale where all individual indicators are considered as outputs and a dummy input (equal to one) is assumed for all countries of study. Moreover, the weights are constrained to a sum less than or equal to 1. Unlike the HDI, the DEA-like approach to the assessment of human development is a relative measure. Hence PNG is compared with best-practice neighbouring countries when assessing its composite performance on the human development indicators weights (Despotis, 2005). We now formulate a simplified index maximizing LP model, which will be used to estimate an ideal value of the HDI of PNG and neighbouring countries. These calculations are then extended through a goal programming (optimization) model to derive a new measure of human development. We assume that the PNG economy has a level of education attainment high enough so that neither income nor illiteracy or poverty rates affect the life expectancy and income per capita as measured in the HDI. Hence, we maximize expenditures on health and income, whilst minimizing illiteracy and poverty rates. We begin by constructing a linear model based on this assumption.

We represent variables of the HDI as follow;

let C be the set of the 4 countries of the study, $j \in C$ stand for any country in C and j_0 stand for the evaluated country;

let w_{HI}, w_{EI}, w_{II} be the unknown weights of the three indices HI, EI and II respectively.

The linear model (1) below estimates the weights w_{HI}, w_{EI} and w_{II} that maximizes the weighted sum of three components of the HDI, for the evaluated country j_0, and it is solved for one country at a time. The weighted sum of the component indices is constrained to be less or equal to one for all countries. The infinitesimal ε ensures that none of the weights takes a zero value (Despotis, 2005).

$$max \quad h_{j_o} = w_{HI}HI_{j_0} + w_{EI}EI_{j_0} + w_{II}II_{j_0} \quad (1)$$

s.t

$$w_{HI}HI_j + w_{EI}EI_j + w_{II}II_j \leq 1, j \in C,$$

$$w_{HI}, w_{EI}, w_{II}II_j \geq \varepsilon.$$

Model (1) is equivalent to an input-oriented, constant returns-to-scale DEA model with three outputs (HI, EI and II) and one dummy input of 1 for all countries (Mahlberg and Obersteiner,2001). Let h_j be the optimal value of the objective function when the model (1) is solved for country j. In this study, we have PNG and its neighbours Australia, Hongkong and Singapore as points of reference for a high human development group. The values h_j are bounded in the interval $[0,1]$. In notation, we let the objective function as a mapping $f: [0,1] \to \mathbb{R}$ defined by the function (1). A country that achieves a score of $h_j = 1$ is called an “efficient unit” in the DEA terminology and the opposite if the score is $h_j < 1$, the country j might be considered as “inefficient”. Thus, if PNG has a low valued h_j in model (1), then it shows a poor performance on human development and such calls for improved policies to cater for increment in the development indicators. The results from this analysis are given in Tables 4 and 5 below. Table 4 is based on 2019 data provided by UNDP report 2020 whilst table 5 is based on the predicted values from table 3.

Table 4: DEA-score for PNG against its neighbouring developed countries.

Country	HDI Rank	HDI	DEA Score
Hong Kong	(4)	0.949	1.000
Australia	(8)	0.944	1.000
Singapore	(11)	0.938	1.000
PNG	(155)	0.555	0.872

PNG's neighbouring developed countries suit well the "best practice" country and "efficient unit" as the DEA score $h_j = 1$ from table 4.

Table 5: DEA-score for PNG (2020-2050) based on predicted values.

Year	2020	2030	2040	2050
DEA Score	0.878	0.919	0.959	1

From table 5, PNG can be referred to as an "efficient unit" between 2020-2040 as the computed DEA score $h_j < 1$, but becomes an "efficient unit" by 2050 as $h_j = 1$.

Linear programming

We formulate the planner's problem from the objective function (1) by rewriting the variables into a matrix. The objective function (2) maximizes the HDI 30-years (2020-2050). The *lpSolve* package from R is used to solve the planner's problem (2). lpSolve contains routine lp (…) to solve linear optimization problems.

$$max\ \ h_{j(PNG)} = max_{w_{HI,}w_{EI,}w_{II}}\ w_{HI}HI + \ w_{EI}EI + \ w_{II}II = \begin{bmatrix} HI \\ EI \\ II \end{bmatrix}^T \begin{bmatrix} w_{HI} \\ w_{EI} \\ w_{II} \end{bmatrix} \quad (2)$$

s.t

$$max_{w_{HI,}w_{EI,}w_{II}}\ w_{HI}HI + \ w_{EI}EI + \ w_{II}II = \begin{bmatrix} HI \\ EI \\ II \end{bmatrix}^T \begin{bmatrix} w_{HI} \\ w_{EI} \\ w_{II} \end{bmatrix} \leq 1.$$

When function (2) is coded, the raw data for 2019 from Table 1 (Figure 2) and approximate values for 2050 from Table 3 (Figure 3) above are substituted as coefficients of the objective function with respect to the weights $w_{HI,}w_{EI}, w_{II}$ to determine the optimal values respectively. The optimal element obtained after solving the objective function (1) through linear programming is now 0.872 as shown in Figure 2.

```r
# Import lpSolve package
library(lpSolve)

## Warning: package 'lpSolve' was built under R version 4.1.1

# Set coefficients of the objective function. The coefficients are derived
from the life expectancy at birth(LEI), expected(EYS) and mean (MYS) of
schooling plus GNI per ca-pita data for the year 20....
f.obj <- c(64.5,0.88,4301)#values can be changed here.
# Set matrix corresponding to coefficients of constraints by rows #according
to predicted values for LEI, EYS & MYS with GNI per capita data #for the year
2050.
# Do not consider the non-negative constraint; it is automatically #assumed
f.con <- matrix(c(74,1.52,12000), nrow = 1, byrow = TRUE)
# Set unequality signs
f.dir <- c("<=")
# Set right hand side coefficients
f.rhs <- c(1)
#Optimal values of LEI, EDI,II
# Variables final values
lp("max", f.obj, f.con, f.dir, f.rhs)$solution

## [1] 0.01351351 0.00000000 0.00000000

#Objective at maximum
lp("max", f.obj, f.con, f.dir, f.rhs)

## Success: the objective function is 0.8716216
```

Figure 2: Objective function solved to a maximum value rounded to:0.872**.**

The general syntax of linear programming in R shown in Figure 3 means the following; *direction* controls whether to minimize or maximize, coefficients **c** are encoded a vector *objective.in*. Constraints A are given as a matrix *const.mat* with directions *const.dir*. Constraints **b** are inserted as a vector *const.rhs.*

```r
lp(direction="min", objective.in, const.mat, const.dir,
   const.rhs)
```

Figure 3: General syntax of linear programming in R.

Results and discussion

The linear program coded in R solved the objective function derived from equations (1) - (2) by obtaining a maximized value of $h_{j(PNG)}$up to 0.872, that is: ##*Success: the objective function is 0.872*. However, some observations can be made from the line of code in Figure 4. This is where the values for LEI, EYS and MYS plus per capita GNI can be changed for each year as data becomes available in future.

```r
# Set coefficients of the objective function. The coefficients are derived
from the life expectancy at birth(LEI), expected(EYS) and mean (MYS) of
schooling plus GNI per ca-pita data for the year 20....
f.obj <- c(62,0.81,3661)#values can be changed here.
```

Figure 4: Coefficients of constraints.

When setting the matrix corresponding to the coefficients of constraints, the coefficient values can vary between 0 and 1 resulting in an arbitrary small number ε. This is possible because the objective function is defined on the mapping $f: [0,1] \to \mathbb{R}$. For instance, observe the change in Figure 5 after inserting new values for LEI, EYS, MYS and per capita GNI from 2010 data (UNDPR.2020) with respect to w_{HI}, w_{EI}, w_{II} to maximize h_j.Such alternates in the coefficients represent individual values of the composite indicators(HI, EI, II) that make up the HDI.

```
# Import lpSolve package
library(lpSolve)

## Warning: package 'lpSolve' was built under R version 4.1.1

# Set coefficients of the objective function. The coefficients are derived
from the life expectancy at birth(LEI), expected(EYS) and mean (MYS) of
schooling plus GNI per ca-pita data for the year 2010.
f.obj <- c(62,0.81,3661)
# Set matrix corresponding to coefficients of constraints by rows #according
to predicted values for LEI, EYS & MYS with GNI per capita data #for the year
2050.
# Do not consider the non-negative constraint; it is automatically #assumed
f.con <- matrix(c(74,1.52,12000), nrow = 1, byrow = TRUE)
# Set unequality signs
f.dir <- c("<=")
# Set right hand side coefficients
f.rhs <- c(1)
#Optimal values of LEI, EDI,II
# Variables final values
lp("max", f.obj, f.con, f.dir, f.rhs)$solution

## [1] 0.01351351 0.00000000 0.00000000

#Objective at maximum
lp("max", f.obj, f.con, f.dir, f.rhs)

## Success: the objective function is 0.8378378
```

Figure 5: Coefficients of constraints can be altered.

Conclusion

The index-maximized LP model was used to generate a new human measure called DEA-score apart from the HDI. PNG neighbouring countries namely Australia, Hong Kong and Singapore were used as best-practice countries to determine whether PNG can be termed as an "efficient" or "inefficient". The result obtained from the PNG DEA-score h_j was less than 1. Hence, PNG can be termed as an "inefficient" country in terms of human development. Moreover, linear programming in R statistical software using *lpSolve* library was used to solve the optimization problem where the result obtained is $h_{j(PNG)} = 0.872$, which falls between 0.7 and 0.9 indicating the expected PNG HDI value by the year 2050, thus achieving its' vision 2050 goal. Thus, PNG has the potential to be ranked as one of the top 50 high human development countries by 2050, which was proven through solving the optimization LP model.

Glossary

UNDP – United Nations Development Programme
HDI – Human Development Index
GNI – Gross National Income
PNG DSP – Papua New Guinea Development Strategic Plan

MTDP – Medium Term Development Plan
LP – Linear Programming
LEI – Life Expectancy Index
EI – Education Index
II – Income Index
BoD-Benefit of Doubt
DEA- Data Envelopment Analysis
HDI_{BOD} –Human Development Index Benefit of Doubt
MBoD-Multiplicative Benefit of Doubt
PNG- Papua New Guinea

Appendices

R-Source Code for linear programming

```
# Import lpSolve package
library(lpSolve)
# Set coefficients of the objective function. The coefficients are derived from the life expectancy at birth(LEI), expected(EYS) and mean (MYS) of schooling plus GNI per ca-pita data for the year 20....
f.obj <- c(64.5,0.88,4301)#values can be changed here.
# Set matrix corresponding to coefficients of constraints by rows #according to predicted values for LEI, EYS & MYS with GNI per capita data #for the year 2050.
# Do not consider the non-negative constraint; it is automatically #assumed
f.con <- matrix(c(74,1.52,12000), nrow = 1, byrow = TRUE)
# Set unequality signs
f.dir <- c("<=")
# Set right hand side coefficients
f.rhs <- c(1)
#Optimal values of LEI, EDI,II
# Variables final values
lp("max", f.obj, f.con, f.dir, f.rhs)$solution
#Objective at maximum
lp("max", f.obj, f.con, f.dir, f.rhs)
```

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