Data Analysis of Reducing CO_2 Emissions by Investing in Family Planning

Client Report

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Executive Summary

This project was commissioned by Population Matters, an environmental non-profit organization. It believes that halting population growth through voluntary family planning and women's empowerment programmes is an essential and cost-effective condition for a sustainable world. Its PopOffsets project addresses climate change by encouraging carbon offset donations for such programmes, thus reducing future energy demand and hence CO2 emissions with each unwanted birth prevented.

The purpose of this project is to analyse in detail a previous model by Thomas Wire (LSE 2009), proposing a cost-benefit analysis of reducing carbon emissions by non-coercively reducing population growth between 2010 and 2050. His report 'Fewer Emitters, Lower Emissions, Less Cost', estimated that $6.46 invested in family planning would abate one ton of CO2 emissions (tCO2). Since his data is six years old, however, assumptions about the cost of contraceptives, population and CO2 emissions may not now be convincing. Thus his data needed updating; and a method was devised to improve his work and explain the large cost differences derived from different approaches.

A cost/effect data analysis of spending on modern contraception methods was explored, aiming to reduce CO2 emissions from 2016 to 2050. For the data analysis, initial assumptions were made, and raw data collected mainly from UN Population Division and from the client. All the numbers of population and CO2 emissions in the figures and tables are presented in thousands.

There are in total five versions of calculation in this report. Recalculating Wire's old data from 2010 to 2050 (version one), and including new data from 2016 to 2050 (version two), found only minor miscalculations in his previous work. Three new versions of method were then analysed. Version three, based on Wire's method but with changed assumptions about CO2 emissions and the cost of meeting unmet contraceptive need, gave a result of $4.2/tCO2 . Version four is based on version three but alters the population assumptions and gave a result of $4.31/tCO2 . Version five, agreed as by far the most credible, is based on version four but takes account of life expectancy. It concluded that investing $1.11 per capita in family planning abates one ton of CO2 emissions.

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1. Introduction

The introduction part will highlight the main purpose of this project; discussing company's background and the main problems that this project could face. The final parts of introduction will discuss proposed approaches and the structure this report will take.

1.1 Objective

This project aims to critically analyse Thomas Wire's paper[1], including its methodology and conclusions, whilst accumulating new data and explaining the huge differences in cost among different methods. The final results could be used to support the organisation's proposition to be presented in national and international bodies.

In order to do this, a cost–effective data analysis of spending in modern contraception methods will be looked at with the aim of reducing CO_2 emissions[2] from 2016 to 2050 being explained.

1.2 Background

1.2.1 PopOffsets

PopOffsets has its origin from a 2009 LSE dissertation by Thomas Wire and has been supported by Population Matters, which is a charity that aims to offset CO_2 emissions by encouraging companies and individuals to donate towards family planning projects; health programs and education of relationship and sex in the world, especially in the less developing countries.

Currently, PopOffsets is the only project in the world that helps individuals and

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[1] Thomas Wire's paper "Fewer emitters, lower emissions, less cost" explains a cost analysis of reducing carbon emitters by supporting family planning from 2010 to 2050. He finished this paper as his master dissertation in 2009.

[2] Carbon emissions is another saying of carbon dioxide emissions, in this study, it also equals to CO_2 emissions or CO_2e. CO_2 is less accurate than CO_2e, which contains more types of emissions.

organisations to offset their carbon footprint by improving family planning[3] provision in both developed and developing countries. The basic concept of the organisation is that there is a strong relationship among increasing carbon dioxide emissions, environmental change and the world population. From PopOffsets previously supported projects, that helped people to avoid unplanned pregnancies is one of the most cost- effective ways of reducing CO_2 emissions.

Therefore, PopOffsets was built to support Population Matters' intention of maintaining a sustainable global population and helping to improve the climate change situation. PopOffsets realises most companies and organisations want to improve their brand image by fulfilling their corporate and social responsibilities. Thus, it believes that companies might be willing to support the reduction of global CO_2 emissions by donating money to family planning projects. Commercial organisations and individuals are both the target customers of PopOffsets. People can easily donate money via their online website[4].

PopOffsets offers an online guide, which enables contributors to easily make online donations. Every organisation that chooses to offset its carbon emissions through PopOffsets will receive a donation certificate confirming the contribution made and the amount of carbon offset. The process is clear that donators can know their total emissions based on different countries' CO_2 emissions per year. From this point, knowledge of the cost of family planning to decrease CO_2 emissions is important.

1.2.2 Problems

Climate change presents a global risk to overall society. From the climate change chapter of a report named *OECD Environmental Outlook to 2050* (Marchal & Dellink, 2011), global greenhouse gas emissions will continue to rise, and in 2010 global CO_2 emissions already reached an all-time high of 30.6 gigatons (Gt).

Marchal and Dellink (2011) suggested that "without more ambitious policies than those in force today, global greenhouse gas emissions will increase by another 50%

[3] Family planning is about when to have children, and the use of birth control to implement it.

[4] Web page about how to donate: http://www.popoffsets.org/calculator.php

by 2050, primarily driven by a projected 70% growth in CO_2 emissions from energy use".

Developed countries are normally criticised for the majority of emissions. However, in recent years, high economic growth will also result in a huge amount of CO_2 emissions in some major emerging economies. Thus, in order to retain a stable global development, it is urgent for countries to reduce emissions through efficient methods.

Several carbon-reducing technologies exist, but family planning could bring more effects at a much cheaper cost level from a report by UNICEF (1992). Thomas Wire (2009) also compared the estimated cost of family planning with other emission-reducing technologies[5], and results showed the total cost of using other methods will be almost five times more than family planning.

PopOffsets basic proposition is mainly based on Thomas Wire's research. However, the result of $6.46 spending in family planning would prevent the emission of a 'ton of CO_2 emissions' from Thomas Wire's work is different with other PopOffsets-supported projects' results. Therefore, a more critical analysis of Thomas Wire's paper and a new fact-based argument should be set up to support PopOffsets' proposition

1.2.3 New Adopted Approach

Version one of recalculation and version two of contemporary calculation will be done to analyse Thomas Wire's method. Three new versions with improvements upon Thomas Wire's approach will be discussed in this report as well. Version three changes the assumptions of cost and CO_2 emissions per capita from Thomas Wire's method, while version four changes the method of forecasting the population. Version five is based on version four but considers the effect of lifetime in the calculation. All versions are basically based on Thomas Wire's method but with improvements to both the benefit model and the cost model. The benefits of this project are the amount of reduced CO_2 emissions, while the cost is the money used to meet the unmet needs

[5] Geo-thermal, Sugar Cane, Reduced Deforestation, Switch-Grass, Wind, Solar, Coal CCS New Built, Coal CCS Retrofit, Plug-in Hybrids, Electric Vehicles

of modern contraceptive services.

Within the benefit part, in order to get the figure of how much CO_2 emissions can be reduced, the number of avoided unintended births through satisfying unmet needs and the figure of CO_2 emissions per capita are important. This process is completed in a consistent method for each year from 2016 to 2050 through a spreadsheet model. CO_2 emissions per capita in each country are estimated for all years to produce a total emission of the proposal approach.

As for the cost part, a spreadsheet model is used to calculate the total need and cost of meeting the unmet needs of modern contraceptives in different countries. Meeting the unmet needs of modern contraceptives can greatly decrease the unintended birth rate and accordingly help to reduce individuals' CO_2 emissions.

Finally, a figure of how much donations in unmet need can reduce one ton of CO_2 emissions can be calculated using the total costs to divide the total reduced CO_2 emissions.

1.3 The Structure of the Report

This report will start with an overview of Thomas Wire's method, followed by a complete update and review of the data used, including any changes in the basis of data recording, processing and an evaluation of Thomas Wire's methodology and assumptions in chapter two.

In chapter three, suggestions of how to improve Thomas Wire' method and the analyses behind the improved approaches and calculations in both benefit and cost calculations will be made through three versions.

A comparison of the different methods will be presented in chapter four. Conclusions and recommendations of this project can be found in chapter five, and some suggestions for further analyses will also be made in this part. The report also lists references and appendices at the end.

2. Thomas Wire's Method

This part will summarise Thomas Wire's method and conduct a complete update and review of the data, which have been used. A critical evaluation and possible suggestions will also be discussed.

2.1 Method Review

Thomas Wire's work consists of two parts: benefit and cost. The adopted approach analyses the benefit of maximally reducing unintended births worldwide against the cost of satisfying unmet needs for family planning. This cost is deemed to be equal to the cost of maximally reducing unintended births on the assumption that any woman giving birth as a result of an unintended pregnancy has an unmet need for family planning by the definition of the term 'unmet need'. The process flow of the model is in figure 1 and the calculation equations are in table 1.

Figure 1: Methodology flow of Thomas Wire's method (Wire, 2009)

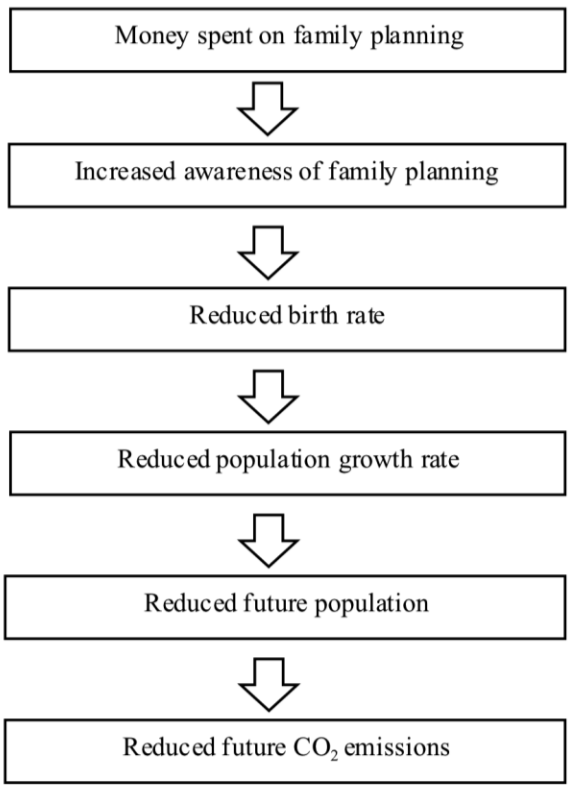


Table 1: **Calculation of Thomas Wire's method**

Part	Step	Contents
Main Equation	A	$/t$CO_2$ e=Total cost in meeting unmet need/Total benefit of CO_2e averted
Benefit Analysis	B	Total benefit=CO_2e before family planning-CO_2e after family planning
	C	CO_2e before or after family planning=original population or family planning population*CO_2e per capita
	D	Family planning population this year =population the year before*exp(population growth rate after family planning)
	E	Population growth rate after family planning =original population growth rate+(original population growth rate in 2010-population growth rate after family planning in 2010)
	F	Population growth rate after family planning in 2010=ln (family planning population this year/ population the year before) /time period[6]
	G	Population with family planning in 2010=original population- averted unintended birth
	H	Averted unintended birth= average unintended birth from 1995-2000*72%[7]
Cost Analysis	I	Cost in meeting unmet need=cost for per capita* total population of unmet need
	J	Unmet need=3% of the world's population
Time: 2010 to 2050, No of countries: 222		

For the benefit part, this method firstly estimates the number of unintended births and family planning level globally by country and then estimates avoided unintended pregnancies from 2010 to 2050. Later, the carbon-tons-emitted per capita by different countries is estimated.

The main assumptions in this part are that the average number of annual unintended births from 1995 to 2000 is proportionally representative of the number of unintended births in the future. CO_2 emissions per capita will not significantly change between 2010 and 2050.

The cost part firstly estimates the population of people who would need to be provided family planning services and then multiplies it with the investment of each

[6] The population growth rate formula is calculated as ln (Pt/P0)/t (United Nations Population Division, 2015).

[7] From Adding It Up (UNFPA, 2003), meeting the unmet need would reduce the number of unplanned births in developing countries by 72%. Assume this figure will also apply on developed countries.

woman. Assumptions in this part are the demand for family planning (unmet needs) will represent a constant proportion of each country, around 3%, and the per-capita-cost of proving family planning will be identical in all countries from 2010 to 2050.

Finally, the cost of preventing each ton of CO_2 emisions emitted can be conducted by dividing the total cost to benefit.

2.2 Version One: Recalculation

Calculation in this part follows with Thomas Wire's original steps, but the number of unintended births is taken from different sources. This project uses the exact data of birth in the next fifty years from United Nations (UN) rather than using the birth level from 1995 to 2000 to present all following years as Thomas Wire's method did (table 1, step H). The new unintended birth will be calculated as:
Averted unintended birth in year N= birth in year N*unintended rate *72%

The source of unintended birth referenced in Thomas Wire's paper is unable to be found. In order to solve this problem, this paper multiplies the unintended birth rate with the birth number of different countries. An article called *Unintended Pregnancy: Worldwide Levels, Trends, and Outcomes* (Singh, et al., 2010) presents the unintended birth rate through different regions and United Nations Population Division (2015) provides the birth number by countries and regions from now to 2100. 222 countries with large populations were selected.

Table 2 compares results between Thomas Wire's and the recalculated version one's. It shows that even though UN population data rather than the population growth rate is used to predict, the results show that there is around $0.06 cost difference, which means there might only have minor errors in Thomas Wire's calculations.

Table 2: Results of recalculate **Thomas Wire's** method (version one)

Method	Total population with unmet need 2010-2050 (000s)	$ Cost/ woman	Total cost($ 000s)	Reduced Total tCO_2e (000s)	$ Cost/ ton
Thomas Wire	9,698,681	22.7	220,160,067	34,070,902	6.46
Version one	10,380,870	22.7	235,645,738	36,847,038	6.40

2.3 Version Two: Up to Date Data Calculation

The calculation process in this part flows with Thomas Wire's method, but estimates the result from 2016 to 2050 rather than from 2010. 233 countries are used instead of 222 in this part, because the UN enlarged its database. Some countries were not labelled with data on CO_2 emissions (CDIAC, 2015) or birth (United Nations, 2015) but still contributed to global population data (United Nations, 2015). Based on GDP level, Thomas Wire's table and locations, this project uses other countries to present them (see appendix C). Thus, the new data result from table 3 is \$6.20/tCO_2e. When compared with Wire's method, it is \$0.26 cheaper to cut per ton of future CO_2 emissions.

Table 3: Results of up to date **Thomas Wire's method (version two)**

Year	Total population with unmet need (000s)	\$ Cost/ woman	Total cost (\$ 000s)	Reduced tCO2e	\$ Cost/ ton
Version two (2016 to 2050)	8,784,061	22.7	199,398,183	32,150,756	6.20
Thomas Wire (2010 to 2050)	9,698,681	22.7	220,160,067	34,070,902	6.46

2.4 Evaluation

Thomas Wire's paper is six years old and gaps in costs from other research make it essential to check the old method and ascertain the possible reasons for such huge differences. There are some calculations and assumptions, which seem unreasonable in Thomas Wire's method.

- Cost of contraceptives: applying a stable average cost of meeting unmet needs to all countries will produce a rough result and the real costs will change in the future.
- CO_2 emissions: CO_2 emissions levels for each country from now to 2050 will change, but Thomas Wire assumed it would be stable in the future.
- Population: unmet needs will not only be a non-changeable percentage of the total population in the future, 3% in Thomas Wire's work.

3. New Improved Method

This part gives methods which have improved assumption flaws in Thomas Wire's method. The conceptual flow of new methods follows Thomas Wire's as shown in figure 1. There are three new method versions, which are developed step by steps. The last method described will be the final method adopted for this project. Detailed information will be reviewed in the following sections.

3.1 Basic Assumptions

In order to simplify the calculation and research processes, some assumptions are made at the beginning. It is assumed that:

1. CO_2 emissions per capita and annual birth rate of smaller countries can be substituted by other countries, which are based on previous studies, locations and GDP. Countries are listed in appendix B.
2. Meeting unmet needs will reduce unintended births by 72% as predicted.
3. The trend of CO_2 emissions in some specific countries from developed and developing areas can be used to present trends of other countries.
4. The cost of meeting unmet needs will increase from 2016 to 2050.
5. The calculation of unmet needs will not consider the results from the UN dataset and real situations but rather a simple stable percentage of total population.
6. Population growth rate formula can be used to calculate population.

3.2 New Method: Version Three

This part amends those unsuitable assumptions from Thomas Wire's in chapter two and will provide a description of how benefit analysis and cost analysis are carried out. Analyses are all based on medium fertility, which is the most likely situation.

3.2.1 Processes of Calculation

Table 4 shows the analysis process and types of data collected in both the benefit and cost analyses. For the benefit analysis, version three basically follows Thomas Wire's method but with changes of the CO_2 emissions per capita in Step K, which used to be constant in the future from Thomas Wire's. As for the cost part, changes from

Thomas Wire' method are the cost for investing per women to fully satisfied the unmet needs and the total population of woman with unmet needs (Step I and J).

Table 4: Calculation of version three method

Part	Step	Content
Main Equation	A	$/t$CO_2$ e=Cost in meeting unmet need/Benefit of amount of CO_2e averted
Benefit Analysis	B	Benefit=CO_2e before family planning-CO_2e after family planning
	C	CO_2e before/after=original/with family planning population*CO_2e per capita
	D	Family planning population =population of the year before*exp(population growth rate after family planning)
	E	Population growth rate after family planning =original population growth rate+(original population growth rate in 2010-population growth rate after family planning in 2010)
	F	Population growth rate after family planning in 2010=ln (family planning population this year/ population the year before /time period
	G	Population with family planning in 2010=original population- averted unintended birth
	H	Averted unintended birth= birth*unintended rate *72%
Cost Analysis	I	Cost in meeting unmet need=cost in 2016* annual increase rate* total population of unmet need
	J	New unmet need=original unmet need/original population*New population
Benefit Analysis	K	CO_2e per capita in year n=CO_2e in 2011*(1+annlual emission growth rate)$^{\text{Time period}}$
Time: 2016 to 2050, No of countries: 233		

The following part shows the benefit analysis process. It explains each step's calculation and data types:

K.1: Enter the average number of CO_2 emissions emitted per capita per year of each country from CDIAC. The latest data can be found is in 2011.

K.2: Obtain the annual increase rate of CO_2 emissions of developed, fast increasing developing economics and the rest of the world (ROW).

K.3: Use the figure from 2 and 1 to obtain the CO_2 emission each year each country in the following 35 years.

H.4: Input the annual intended births from each country based on UN data.

H.5: Get the unintended birth by multiplying birth numbers and the unintended rates by regions.

H.6: Multiply the unintended birth of 72%, which is the maximum rate of unintended birth that can be avoided.

G.7: Use population to minus the avoided unintended birth figure to get the new population figure.

F.8: Calculate the population growth rate without and with family planning in 2016.

E.9: Use old population growth rate to minus the new population growth rate in step 8 in order to get a growth rate difference.

E.10: Add the difference to the old population growth rates for each country from 2016 to 2050.

D.11: Follow the formula of population growth rate to get the new population after fully meeting the unmet need.

C.12: Multiply the new population with the CO_2 emissions of each country each year. And sum up the new amount of total CO_2 emissions.

C.13: Enter each country's future population level projection from 2016 to 2050 from the UN population division database. And sum all projected population levels for each country.

B.14: Get the total reducing amount of CO_2 emissions by using the figures of total CO_2 emissions without family planning and with family planning.

After getting the reduced CO_2 emissions, the cost analysis will be calculated in Step J and Step I in the table, and detail calculation process is as below:

J.1: Enter unmet needs of modern contractions from UN dataset.

J.2: Get the percentage of unmet need in the total UN population.

J.3: Use the percentages in stage 2 of other countries to substitute those do not have unmet needs data from UN database. Multiply the percentages and new population of those countries to get new unmet needs. Detailed country list can be found from the appendix B.

J.4: Multiply the percentage from 2 and 3 with the new population from benefit analysis to get the new unmet needs.

I.5: Obtain the cost of meeting unmet need of modern contraception from Adding It Up (2014) and another report called *Contraceptive Needs and Services* (Sonfield, et al., 2010).

I.6: Calculate the annual increase rate of cost per person per year and use this rate in the following years in order to predict the cost of each country from 2016 to 2050.

I.7: Multiply the cost in stage 6 with the number of new unmet needs in stage 4 to get the cost of unmet need for each country.

At the end, this analysis can produce a figure of \$/tCO_2e by using the total reducing CO_2 emissions and total cost of meeting unmet need (Step A).

3.2.2Benefit Analysis

From the stages of the benefit analysis, it is shown that the final amount of reduced CO_2 emissions is the difference between the total CO_2 emissions produced without meeting unmet needs and meeting unmet needs.

Table 5 shows the key elements used to calculate the family planning proposals. Eight countries, which Thomas Wire selected to illustrate the purpose of the implementation, are also used here. Total population summed all yearly population from 2016 to 2050. The emission for each country is collected from CDIAC (2015). The total CO_2 emissions in the following 35 years are also summed in this table.

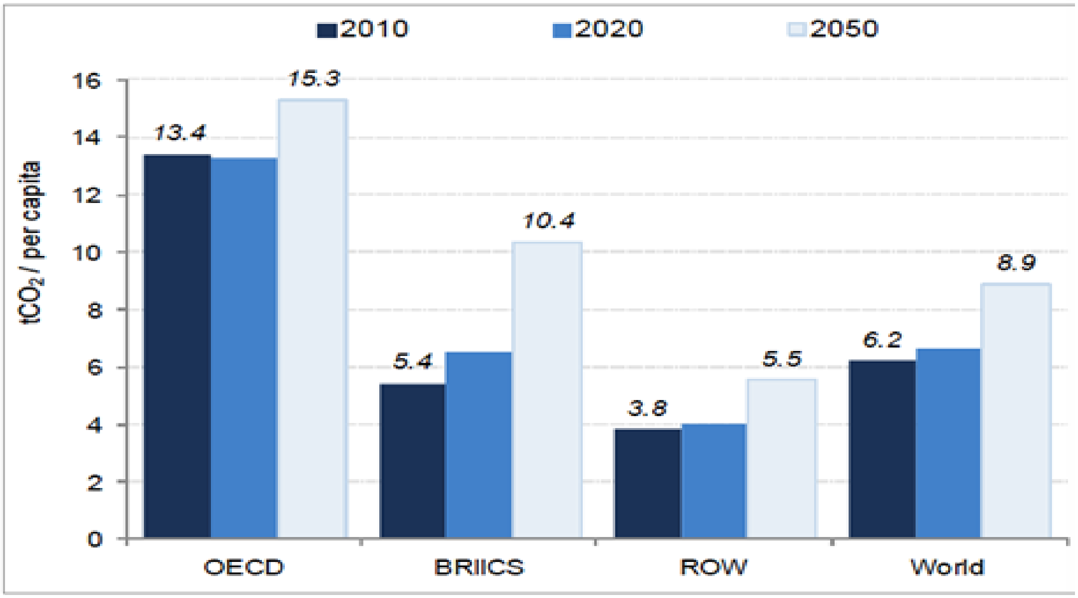
Table 5: Projected population and CO_2 emissions for selected countries with no population control

Country	Total population 2016-2050 (000s)	tCO_2e emitted per capita 2011 (CDIAC, 2015)	Total tCO_2e 2016-2050 (000s)
Kenya	2461258.340	0.330	1018948.142
China	48875883.058	6.601	408239752.491
Afghanistan	1593467.438	0.403	802153.691
India	54112661.031	1.687	116391368.966
UK	2475017.329	7.187	21466208.460
Guyana	28372.866	2.237	78208.410
Bermuda	2038.462	6.051	4028.328
USA	12586413.251	16.648	69026295.690

The 233 countries' medium fertility level population figures in the period from 2016 to 2050 are from UN data (2015). Each country is calculated to find the total number of people living in the years 2016 to 2050. CO_2 emissions emitted per capita of 2011 are also listed in table 5. Because the most recent data of CO_2 emissions is from 2011, it is critical to find the trend of CO_2 emissions in the next 35 years.

Figure 2 shows the estimated GHG emissions per capita from 2010 to 2050 of OECD[8], BRIIICS[9] countries (a country list can be found in the appendix B). The OECD report (Marchal & Dellink, 2011) explains that "any projection of future emissions is subject to fundamentally uncertain factors, such as demographic growth, productivity gains, fossil fuel prices and energy-efficiency gains". The scenario suggests that GHG[10] emissions will continue to grow until 2050. Thus, CO_2 emissions are not stable.

Figure 2: GHG emission per capita: Baseline, 2010-2050



Source: OECD Environmental Outlook Baseline; output from IMAGE/ENV-Linkages (OECD, 2015).

Emissions from BRIICS countries are expected to account for most of the increase in the future. This is caused by growth in population and GDP per capita, leading to growing per-capita GHG emissions. In the OECD, emissions are expected to grow at a slower speed, which can reflect demographic decline and existing climate policies.

In the country list, OECD countries are the most developed countries while BRIICS are the fastest growth developing countries. Therefore, it could be safe to use the growth rate level of these two groups to present other similar countries. Although this figure describes GHG emissions rather than CO_2 emissions, the percentage of CO_2 emissions in the GHG emissions are stable, and represent around 75% of total GHG emissions. The per capita emissions of developed countries will decline until 2020, but will increase later. This might be due to the fact that decline of population growth rate of developed countries is much higher than the reduced rate of CO_2.

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[8] Country list and definition are explained in the appendix B.

[9] Country list and definition are explained in the appendix B.

[10] A greenhouse gas sometimes called GHG.

This results in a situation where governments are using policies to reduce CO_2 emissions but the per capita rate of CO_2 is still growing. As for developing countries, their population growth rate might continue to increase but their emission growth rate will increase at a much higher speed. Detailed calculations about how to get the annual growth rate from 2010 to 2050 will be discussed in appendix A.

When the sum of all countries projected CO_2 emission tons emitted globally from 2016 to 2050 is calculated, the result shows that a total of 1,352,432,694,040 tons of CO_2 emissions will be produced.

The purpose of the proposal of avoiding unintended birth is to reduce the impact of unintended births on CO_2 emissions. When calculating the new population with birth control, the methodology is the same as Thomas Wire's. Based on the 2016 projected population level, the difference between the new population growth rates of population control and the old growth rates without family planning will be the effect of preventable unintended births on the birth rate. Applying this difference to all the following year's population growth rates and new populations after providing contraceptive services can be calculated based on the population growth rate formula[11]. Table 6 shows results of eight selected countries after family planning.

Table 6: Projected population and CO_2 emissions for selected countries with population control

Country	Total population 2016-2050 (000s)	tCO_2e emitted per capita 2011 (CDIAC, 2015)	Unintended birth rate%	Total tCO_2e 2016-2050 (000s)
Kenya	2461258.340	0.330	21	935391.6644
China	48875883.058	6.601	12	402397895.7
Afghanistan	1593467.438	0.403	12	766305.2248
India	54112661.031	1.687	12	112525333.9
UK	2475017.329	7.187	11	21125123.34
Guyana	28372.866	2.237	28	70956.92942
Bermuda	2038.462	6.051	23	3889.026204
USA	12586413.251	16.648	23	66352258.07

[11] Population growth rate=ln (population at the end of the year / population at the beginning of the year)/ t

Based on the new population and the CO_2 emission levels between 2016 and 2050, the new total CO_2 emissions will be 1,318,587,610,520 tons. Therefore, 33,845,083,520 tons of CO_2 emissions can be reduced.

3.2.3 Cost Analysis

This part will describe in detail the work carried out to estimate the total cost of providing family planning to meet the unmet needs of modern contraceptive methods.

In 2014, more than half of women of reproductive age in developing regions wished to avoid pregnancy. However, 25% of these women (225 million) were not using effective contraceptive methods. These women, identified as having an unmet need for modern contraception, account for 81% of all unintended pregnancies in developing regions according to Adding It Up (2014).

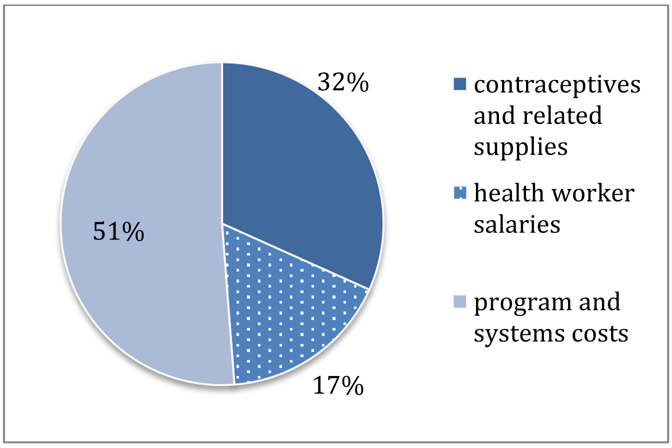
Adding It Up (2014) suggests that traditional methods might be unaffordable to meet people's full needs, and might not useful enough to meet the target of 72% unintended births avoided. As one aim of the project is to prevent as many unintended births as possible, meeting modern contraceptive needs will be more effective than meeting only basic family planning needs. Thus, this paper will focus on unmet needs of modern contraceptive methods rather than basic family planning needs.

Adding It Up (2014) made an estimation of annual costs. It would cost only $25 per woman, or $7 per person in the developing countries, to provide all women with a total package of sexual and reproductive health care. As for modern contraceptive methods, the average annual cost per current user in the developing world in 2014 is $3.18 in direct costs with a total of $6.35 when indirect costs are factored in. With the ratio of that, the costs can be divided into two scenarios: for only providing modern contraceptive and for providing both contraceptive and healthcare services. If providing both sexual and reproductive health services for all women and new-borns, the structure of the cost will be 25.4% for contraceptive services with 74.6% for maternal and new born care (live births), care for women with miscarriages and stillbirths, abortion-related care, HIV-related care for pregnant women and their new-borns, and care for women with other STIs.

These costs vary greatly by region: the average total cost per user is lowest in Asia with only $4.76, where more than half of users are located; while it is $10.65 in Africa and $13.44 in Latin America and the Caribbean. The cost of the full package of care in the USA is $257 per woman (Sonfield, 2010) and the cost for only meeting the unmet needs of modern methods is around $65.28 in average. This number will be used when considering other developed countries.

If provided with both sexual and reproductive health care, the average cost will be $25 per person in 2014, while if only provided with modern contraceptive services, the cost will drop to only $6.35 per capita in developing countries (Adding It Up, 2014). Detailed components of the costs are shown below in figure 3.

Figure 3: Cost of modern contraceptive services



This estimate includes the direct costs of contraceptives and related supplies and health worker salaries, and program and systems costs (also called indirect costs). Indirect costs include various types of program support, such as staff supervision and training, information and education on family planning, construction and maintenance of facilities, development and maintenance of commodity supply systems, and other management functions.

Cost per person to meet unmet need should not be the same in different countries and it will change in the future. According to Adding It Up reports, in 2012 the average cost of meeting modern contraceptives was $9.31, while in 2014 it was $10.77. Thus, the annual increase rate will be 7.56%, using the equation: $(10.77/9.31)^{1/2} -1$. With this increasing rate, the costs are collated to produce an estimated total cost of the entire proposal from 2016 to 2050, which is $142,220,962,430.

To complete the cost-emission analysis, the total cost is divided by total emissions. The results show that $4.2 per capita in providing modern contraceptive can reduce one ton of CO_2 emissions. Total population of women from 15 to 49 with unmet needs is 7,580,565 thousands. Total cost will be $142,220,962 thousands while 33,845,083,530 ton of CO_2 emissions can be reduced.

Table 7: Results of version three method

Total population with unmet need 2016-2050 (15-49)(000s)	Total cost ($000)	Reduced tCO_2e (000s)	$ Cost/ ton
7,580,565	142,220,962.43	33,845,083.53	4.2

3.2.4 Evaluation

The $4.20/$tCO_2e$ is still different from other PopOffset supported project results. For the benefit analysis, version three follows Thomas Wire's method to use the different population growth rate between with and without birth control during specific periods to assume that all the population growth in the following years will follow this trend. Use this assumption to predict new population is rather inaccurate. Therefore, a new method with fewer assumptions and more official data should be devised.

3.3 Version Four

This version focuses on improving the new birth and unintended birth forecasting methods. This part uses a new calculation method rather than the population growth rate used by Thomas Wire.

The new method utilises population and birth data from the UN and assumes that the number of reduced unintended births each year should be deleted in the following years from UN's population data. If that child is not born, he/she cannot be calculated into the population in the future. Their average lifetime will be longer than the forecasting period, 35 years, in this project. In this part, the number of annual births and estimated population from 2016 to 2050 will be collected from UN data. The cost part will have same calculation steps as the version three has. Table 8 shows the analysis steps for version four. Because this version directly uses the data from UN, Step D to Step F from Version three will not be used here. Main changes are in Step H.

Table 8: Calculation of version four

Part	Step	Content
Main Equation	A	\$/tCO_2e=Cost in meeting unmet need/Benefit of amount of CO_2e averted
Benefit Analysis	B	Benefit=CO_2e before family planning-CO_2e after family planning
	C	CO_2e before/after=original/with family planning population*CO_2e per capita
	G	Population with family planning=original population- averted unintended birth
	H	Averted unintended birth= birth*unintended rate *72%
Cost Analysis	I	Cost in meeting unmet need=cost in 2016* annual increase rate* total population of unmet need
	J	New unmet need=original unmet need/original population*New population
Benefit Analysis	K	CO2 per capita in year n=CO2 in 2011*(1+annlual emission growth rate)$^{\text{Time:year of difference}}$
Time: 2016 to 2050, No of countries: 233		

3.3.1 Processes of Benefit Analysis

The process of cost calculation is the same as the version three, but there will be some differences in the benefit calculation, mainly in the Step H part:

H.1: Input the annual intended births and population from each country based on UN data. Get percentages of this year's birth / last year's population based on UN data.

H.2: Get the 2016 unintended birth by multiplying 2016 birth numbers and the unintended rate by regions.

H.3: Multiply the unintended birth of 72%, which is the maximum rate of birth that will be avoided.

H.4: Use 2016 population to minus the avoided unintended birth number and get the new 2016 population figure.

H.5: Use the percentage of 2017 from stage 1 to get the 2017 new birth (2017 percentage=2017 new birth/2016 new population).

H.6: Follow above stages to get each year's new unintended birth, birth and populations.

Then multiply the new population with the CO_2 emissions of each country each year and summed up the new amount of total CO_2 emissions and get the total reducing amount of CO_2 emissions as version three.

3.3.2 Evaluation

Based on the new population and CO_2 emission levels between 2016 and 2050, the new total CO_2 emissions will be 1,324,505,097.602 tons. 31,469,341.090 tons CO_2 emissions can be reduced. The population with unmet needs is 7,433,258,915.

This method could show that with the birth control project, the population will decrease (Figure 4) and the gap of population difference will be larger in the future. Figure 5 shows the difference of CO_2 emissions each year when using family control.

Figure 4: Version two populations change (000s)

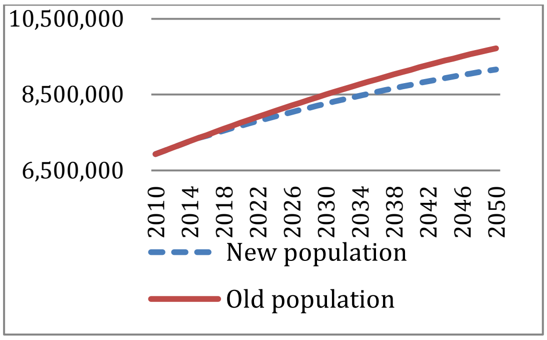
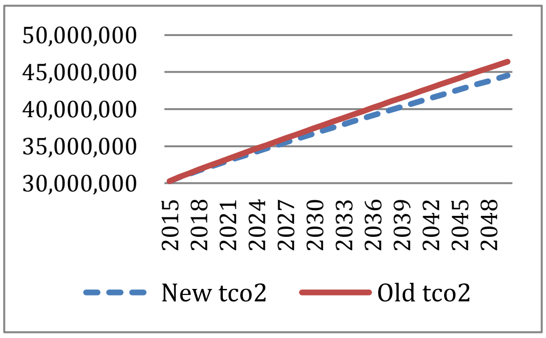


Figure 5: Version two tCO_2e change (000s)



The main method for finding the cost/tCO_2e is to divide the total costs with the difference in CO_2 emissions between with and without family planning. However, as the average human lifespan is much longer than 35 years (the testing period in this paper), even for the least developed countries, this method do not take into consideration the full effects of family planning, and the average costs of this method will be much higher.

3.4 Version Five

All calculations in this part is based on version four, expect it will consider the life expectancy of people in different regions and the cost analysis part will still follow the previous method. Therefore, Step B, C will be different from version four. Table 9 shows the calculation of version five.

Table 9: Calculation of version five

Part	Step	Content
Main Equation	A	$/t$CO_2$e=Cost in meeting unmet need/Benefit of amount of CO_2e averted
Benefit Analysis	B	Benefit=total CO_2e after family planning
	C	CO_2e after family planning= new population with family planning*CO_2e per capita*lifetime in each country
	G	Population with family planning=original population- averted unintended birth
	H	Averted unintended birth= birth*unintended rate *72%
Cost Analysis	I	Cost in meeting unmet need=cost in 2016* annual increase rate* total population of unmet need
	J	New unmet need=original unmet need/original population*New population
Benefit Analysis	K	CO_2e per capita in year n=CO_2e in 2011*(1+annlual emission growth rate)$^{\text{Time: yearof difference}}$
Time: 2016 to 2050, No of countries: 233		

3.4.1 Processes of Benefit Analysis

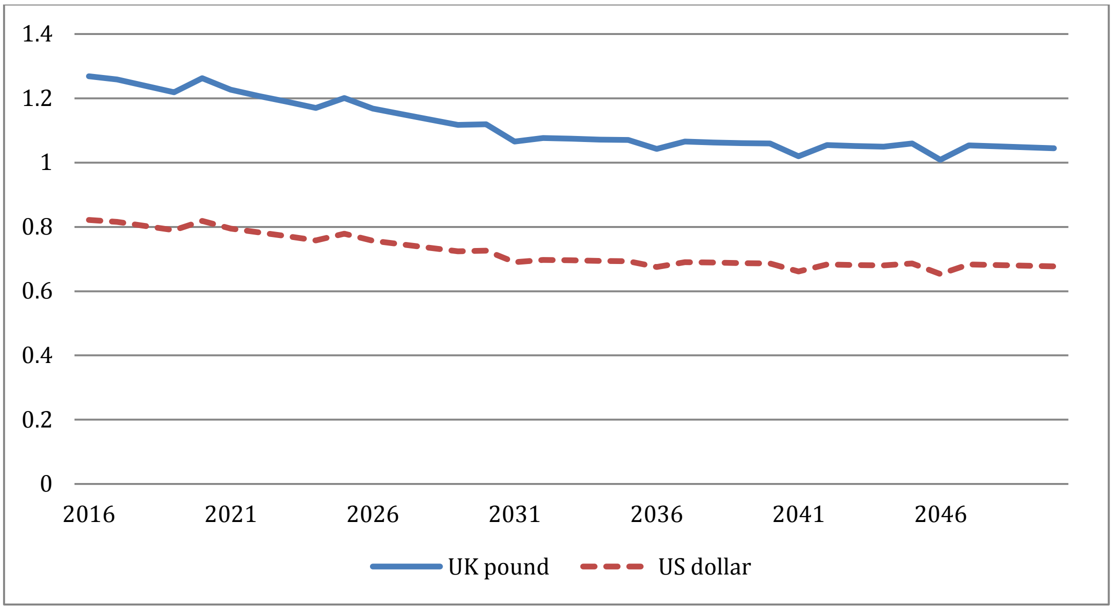
Basic calculations can follow the steps in version four, while the new improvements for this part focus on Step B and C:
C.1: Get the expected lifetime data from 2016 to 2050 from UN data.
C.2: Multiply the life length with the avoided birth and the CO_2 emissions each year.
B.3: Sum the number from stage 2 and get the total number of reduced CO_2 emissions.

Then use the same method from version four to get the total cost and divide the total cost with total CO_2 emissions to get the cost result.

3.4.2 Evaluation

The unmet needs and population in this method will be the same as version four, but the average costs will be much lower because the total reduced CO_2 emissions in the calculation consider the entire lifetime impact of avoided births. The new average cost to cut one ton of future CO_2 emissions is $1.11 (£0.79) between 2016 and 2050.

Figure 6: Cost of averted one tCO_2e from 2016 to 2050 in difference currencies



4. Comparison

4.1 Comparison among This Project Methods

In the comparison part, four key elements: the total population with unmet needs for modern contraceptives, total costs, total reduced CO_2 emissions and cost/tCO_2e are shown in table 10. For the listed six methods, Thomas Wire's original method and recalculation focus on a period from 2010 to 2050, while the other four methods are all calculated from 2016 to 2050.

Firstly, see the results from Thomas Wire's updated data method (version two). The total costs and unmet needs for this part are larger than those in the new methods. The main reasons are that unmet needs in Thomas Wire's method are at an unchangeable rate of around 3% of the total percentage and the cost per woman is also an unchangeable number over the whole forecasting period.

Furthermore, the population forecasting method without considering lifetime effects from version one to version three makes the result higher than in reality. Version four also fails to consider the full lifetime influence of avoiding a birth, and the outcome is still incorrect. However, it can tell the amount of reduced CO_2 emissions in a specific year with birth control when compared with a year without birth control. After considering all of the aforementioned issues, version five might be the better one.

Table 10: Comparison among different methods

Method	Total population with unmet need (15-49)(000s)	Total cost ($000)	Total reduced tCO_2e (000s)	$ Cost/ ton
Thomas Wire	9,698,681.37	220,160,067.24	34,070,902.00	6.46
Version one: recalculation	10,380,869.52	235,645,738.15	36,847,037.59	6.40
Version two: up to date	8,784,060.91	199,398,182.71	32,150,756.48	6.20
Version three	7,580,565.00	142,220,962.43	33,845,083.53	4.20
Version four	7,433,258.92	135,640,792.00	31,469,341.09	4.31
Version five	7,433,258.92	135,640,792.00	122,136,348.03	1.11

4.2 Comparison between the Adopted Method and Other Method

This part will compare results between a new adopted method in this project and another PopOffsets supported analysis. Possible explanations for the difference will be discussed.

From a PopOffsets supported analysis, if based in the UK, the cost will be £0.35/tCO_2e. Table 11 shows the results of the final selected method (version five) of this projectand a PopOffset-supported method. Assuming that life expectancy and emissions per capita will not change, the cost result for PopOffsets is £0.35, yet it is £0.82 in the new method.

Table 11: Comparison between selected method and PopOffsets supported method

Method	£Cost of averting a birth by birth control	Emissions (tCO_2e) per capita	life expectancy	Lifetime tCO_2 at present rates (000s)	£Cost/ tCO_2e
PopOffsets	225.54 (2015)	8 (annual)	80.5 (2015est)	644	0.35
Version five	492 (2016)	7.4 (2016)	80.95 (2016est)	599.03	0.82

If using the same cost of averting a birth, the cost of version five will be £0.37, showing no substantial difference between the two methods. Thus the main reason of final cost difference appears to stem from how to estimate cost to avert a birth at the beginning.

In order to find the cost of averting a birth, total investment and total avoided birth should be known. Total investment is found from the number of unmet needs and the cost of providing them with products and services. The total avoided birth is calculated from the birth and unintended birth rate and 72% of the maximum avoided rate.

Because the 72%, unintended birth rate, unmet needs and the birth statistics have been collected from official reports and organisations, they are trustable. The main problem might be caused by the calculation of costs to meet unmet needs in the project.

In this report, the costs of meeting modern unmet needs in Africa, Asia and Latin America are taken from Adding It Up (2014). The costs of Asia are used to represent Melanesia, Micronesia and Polynesia's costs, because of their similar level of economic development. Using the USA's level to present other developed countries might be unsuitable. As for Thomas Wire, he applied the average costs from developing countries to all countries, which might be more radical.

The second possible reason might be the composition of costs. As seen in the version five method, 32% are for suppliers and products, 17% are for labour and 51% are for other factors. This assumed percentage might be very different in PopOffsets other supported projects. Therefore, the results will be substantially different.

The PopOffsets other supported method is determined by CYP[12]. CYP is the estimated protection provided by contraceptive methods during a one-year period. After ascertaining the CYPs for each contraceptive method, the sum is calculated over all methods in order to obtain a total CYP figure. The CYP figure differs greatly between different contraceptive methods. Thus, if countries use different contraceptive methods, their one CYP equivalent of births averted will vary a great deal. However, this report uses the same 72% birth avoided rate for all countries and assumes that the protection from contraceptive methods will be same.

However, the fundamental difference is that this project focuses on a global level and not only a small range of specific countries. Thus, an individual country's result might not be comparable with the global result.

[12]The detail information and the RESPOND Project updated the CYP conversion factors can be found from: http://www.cpc.unc.edu/measure/prh/rh_indicators/specific/fp/cyp

5. Conclusions and Recommendations

5.1 Conclusions

From the above analyses, the result of using similar sources to recalculate Thomas Wire's method (version one) is $6.40 per capita to cut one ton of CO_2 emissions, which is $0.06 different from Thomas Wire's result. When updating the data to 2016 (version two) , which was released by the UN Population Division at the end of July 2015, the new result is $6.20 per capita to cut one ton of CO_2 emissions. However, this figure can only confirm the correctness of the calculation and not the suitability of the methodology.

The new adopted methods use as much existing data from both national and global organisations as possible. Three possible versions are analysed in the report. In the version three method, the cost is $4.20/t$CO_2$e, while the cost is $4.31/t$CO_2$e in the improved version four method. The results show that the new version five method can produce a lower cost. Spending $1.11 on medium fertility population control can reduce one ton of CO_2 emissions.

From the comparison part, this report suggests that using constant CO_2 emissions per capita and cost for meeting unmet needs, ignoring of life expediency and using unsuitable population forecasting method caused the high result from Thomas Wire's method. Moreover, the data quality of cost to help women to meet their unmet needs for modern contraceptives is the main reason for the result difference between the adopted version five method in this project and another PopOffsets supported project.

5.2 Suggestions for Further Analysis

Different data resources can result in different predicted populations and costs, and accordingly greatly influence the final cost. The different methods of calculating the cost cause the results to vary a great deal. Therefore, it would be better to check these methods' results by using the same list of countries' unmet needs costs per woman.

In this analysis, many small countries have no birth or CO_2 emissions data. Although most of these countries are small, they still have an influence on the result. Further real data could be inputted into the model in the future, if possible.

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Appendix A: Calculation

This appendix includes explanations of several calculations used in the analysis. All sections of this appendix have been referred in the report.

6.1 CO_2 Emission Growth Forecasting

This report assumes that the CO_2e growth rate will be stable in the future. Because the CO_2 emissions of 2010 and 2050 have already been predicted from the published report, use the figure of 2050 and the figure of 2010 can get the annual increase rate. Since the CO_2 emission level of 2011 for each country can be found, thus it can predict emissions from 2016 to 2015 for each country based on the emission increase rate.

For example:

CO_2e of BRIICS countries in 2010 is 5.4 per capita and 10.4 per capita in 2050.

2050 level = 2010level*(1+CO_2e growth rate) ^{40}

Thus, CO_2e growth rate = (10.4/5.4) $^{(1/40)}$-1

2016 CO_2e level =2011CO_2e level*(1+ CO_2e growth rate) ^{5}

Table 12: CO_2 emissions growth rate by different regions

Years	Developed countries	Developing countries	ROW
2010-2020	-0.15%	1.65%	0.93%
2020-2050	0.33%	1.71%	0.51%
2010-2050	0.49%	1.63%	1.07%

6.2 Population Growth Rate

Projected population in the future is based on the population growth rate formula. Population growth rate=ln (population at the end of the year / population at the beginning of the year)/t. t is the length of the period, and it will be "1" in the calculation.

For example: if the growth rate after meeting unmet need is 3.0%, then the new population of 2010 =population of 2009*exp (3.0%).

6.3 Cost Calculation

If the average cost in 2012 is \$9.31, while \$10.77 in 2014, then the annual growth rate= $(10.77/9.31)^{1/2}$-1=7.56%. Thus, future cost can be calculated according to with rate.

Use 2015 Burundi as an example to do cost calculation:
Cost of 2015=cost of 2014 *(1+7.56%)*unmet need.

6.4 Reduced Growth Rate with Unmet Need Proposal

2016 projected population level by meeting unmet need of modern contractive = 2016 projected population level-72% of the annual unintended births.

Recall that country's 2015 populations. A new population growth rate can be estimated via a formula. Then a rate difference can be gained if use the old growth rate to minus the new growth rate. On this basis, it was assumed that all projected future growth rates for that country decline by this difference and population levels could be estimated accordingly.

Appendix B: List of OECD and BRIICS Countries

The Organisation for Economic Co-operation and Development (OECD) aims to promote policies that will improve the economic and social well-being of people around the world (OECD, 2015).

Here is a list of the current member countries of the Organization:

- Australia
- Austria
- Belgium
- Canada
- Chile
- Czech Republic
- Denmark
- Estonia
- Finland
- France
- Germany
- Greece
- Hungary
- Iceland
- Ireland
- Israël
- Italy
- Japan
- Korea
- Luxembourg
- Mexico
- Netherlands
- New Zealand
- Norway
- Poland
- Portugal
- SlovakRepublic
- Slovenia
- Spain
- Sweden
- Switzerland
- Turkey
- United Kingdom
- United States

BRIICS represent emerging economies of Brazil, Russia, India, Indonesia, China and South Africa.

Appendix C: Substitution of Omitted Data

The following countries in the left were not identified with data on CO_2 emissions, birth rate and family planning unmet needs, but contribute to the global population data used in this project.

Data from countries in the right are used as substations for the countries with omitted data.

Table 13: Substitution of omitted data based on GDP (The Word Bank, 2015)

Location	Data Substituted from	Emission	Birth rate	Unmet need
Bermuda	Switzerland		Birth rate	Need
Cayman Islands	United state		Birth rate	Need
Dominica	Peru		Birth rate	
Marshall Islands	Tuvalu		Birth rate	
Palau	Maldives		Birth rate	
Puerto Rico	Spain			
South Sudan	Zambia	CO_2		
Aruba	UK			Need
Luxembourg	Kuwait			Need
Cyprus	Spain			Need
Brunei Darussalam	Singapore			Need
Curaçao	Aruba			Need
Seychelles	Russian Federation			Need
Sint Maarten (Dutch part)	Aruba		Birth rate	Need
Micronesia (Fed. States of)	Sao Tome and Principe			Need

Table 14: Substitution of omitted data based on location and economic development

Location	Data Substituted from	Emission	Birth rate	Unmet need
Western Sahara	Morocco	CO_2		Need
State of Palestine	Jordan	CO_2		
Channel Islands	United Kingdom	CO_2		Need
Caribbean Netherlands	Aruba	CO_2	Birth	
Caribbean Netherlands	United Kingdom			Need
Curaçao	Aruba	CO_2		
Micronesia (Fed. States of)	Indonesia			Need
New Caledonia	Vanuatu			Need
United States Virgin Islands	British Virgin Islands	CO_2		
Faeroe Islands	Iceland		Birth	Need
Gibraltar	Spain		Birth	Need
San Marino	Italy			Need
Liechtenstein	Austria		Birth	Need
Monaco	France		Birth	Need
French Polynesia	Cook island			Need
French Guiana	Guyana			Need
Turks and Caicos Islands	Haiti		Birth	
Greenland	Iceland		Birth	Need
Cook Islands	Fuji		Birth	
Holy See	Italy	CO_2	Birth	Need
Other	Average of Asia	CO_2		Need
Saint Helena	Angola		Birth	Need
Falkland Islands (Malvinas)	Argentina		Birth	Need
Saint Pierre and Miquelon	United States		Birth	Need
Nauru	United States		Birth	
Niue	Tonga		Birth	Need
Tokelau	Samoa		Birth	Need
Tuvalu	Samoa		Birth	
Wallis and Futuna Islands	Fiji		Birth	Need
China, Macao SAR	Hong Kong			Need
Iceland	United Kingdom			Need
British Virgin Islands	United States Virgin Islands		Birth	Need
Montserrat	United States Virgin Islands		Birth	
Saint Kitts and Nevis	United States Virgin Islands		Birth	

Table 15: **Substitution of omitted data based on Thomas Wire's paper**

Location	Data Substituted from	Emission	Birth rate	Unmet need
American Samoa	Samoa		Birth rate	Need
Andorra	Spain		Birth rate	Need
Anguilla	United States Virgin Islands		Birth rate	
Guam	United States	CO_2		
Lesotho	South Africa			
Isle of Man	United Kingdom	CO_2	Birth rate	Need
Marshall Islands	United States		Birth rate	
Mayotte	Madagascar			Need
San Marino	Italy		Birth rate	
Northern Mariana Islands	United States	CO_2	Birth rate	Need
Wallis and Futuna Islands	France			