Raising the Quality of Human Life –
A Least Cost Route to Reducing Carbon Emissions

Insights from a System Dynamics Model

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Abstract

As the Kyoto Protocol approaches the end of its validity and as the international community prepares for designing its successor, the pressure to act, for both developed and developing countries, is inexorably building up. Developing countries emphasize that their total emissions may be significant and growing, but their per capita emissions are still very low -- far below those of the developed world. On the other hand, the industrialised countries claim that without some reduction in future emissions from emerging economies, global change cannot be contained within the limits that are considered safe.

This paper looks at how rapid improvements in quality of life among the world's poorest, and specific, carefully designed interventions, through their impact may provide the one common platform that would attract and bring together almost all parties. These interventions would identify leverage points in societies which have the greatest impact for the least cost and disruption. *This paper presents a possible win-win strategy that can bring the competitors in the current game to play to agreed, logic-based and consistent rules. These rules would be derived from a systems analysis that attempts to overcome the northern consumption vs southern population related stand-offs that exist today.*

The Problem

The changes occurring today in our climate systems may well pose the greatest threat that life on our planet has ever faced. The United Nations Framework Convention on Climate Change (UNFCCC), signed at Rio de Janeiro in 1992 already recognized that such a threat could be addressed only through concerted, large-scale action by the entire international community. Subsequent findings by the International Panel on Climate Change (IPCC) and others have alerted us to the alarming acceleration taking place in climate change processes and have highlighted the need to address them with the highest priority and with an urgency measured in time scales that are now down to years, not decades.

Yet, the current state of negotiations among nations to deal with climate change is still stuck in an endless game of passing the buck from one to another.

Among industrialised countries, the disagreements largely relate to issues of establishing somewhat superficial and temporary advantages, such as choice of baselines and reference dates, acceptable CO2 emission targets, time horizons, etc. Between the rich countries and the poor, the disagreements are slightly more fundamental such as historical responsibility, fairness, per capita rights, acceptable tradeoffs between economic “growth” and emissions, etc.

Given the entrenched positions and the strength of vested interests, there appears to be little incentive for opposing parties to come to the negotiating table with a common basis for agreement on even minor issues – other than the need to keep the discussion going. At stake are heavy economic, political and security issues underpinned by the deep commitments of nations and societies to maintaining their respective “way of life” – defined primarily by their lifestyles, consumption patterns and production systems. Supporting these commitments is the firmly held conviction of their political and corporate leaders that changes in this way of life are not acceptable to their electorates or customers, and should such changes become necessary, they ought at best to be the responsibility of others, elsewhere, or at worst introduced at the domestic level gradually and very slowly.

These views led, in the mid-1990s, to the adoption of the Kyoto Protocol, the agreement among nations to cut their respective energy consumption (and thus greenhouse gas emissions) progressively down until they reached an acceptable level. Low-income countries were temporarily exempted from these cuts. Given the gross disparities in energy use that exist among countries, and the accumulated emissions that different countries had been responsible for over the past couple of centuries, a fairer and more equitable agreement would presumably have been based on what has since come to be called “contraction and convergence”[1], aiming to bring, over a reasonable time period, the per capita emissions of all countries to a common level that is below the threshold that could cause unacceptable climate change.

However, given the asymmetries in negotiating strength in international fora, the agreement actually adopted at Kyoto specified each party’s obligation in terms of how much it must reduce its carbon dioxide emissions in comparison with the levels that existed in that country in the year 1990. The Kyoto Protocol is an unusual instrument of international law, operating on a principle – requiring each party to make a percentage-based reduction in existing consumption levels – that actually perpetuates the gross inequalities of energy consumption among nations. The logic of this approach leads to the need to define “baselines”, “additionality”[2] and other concepts all of which introduce large amounts of ambiguity, room for interpretation and ad hoc reasoning, usually biased in the direction of short-term self-interest.

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[1] Contraction and Convergence, Global Commons Institute

[2] Boyd, E. et al (October 2007). "The Clean Development Mechanism: An assessment of current practice and future approaches for policy".

As the Kyoto Protocol approaches the end of its validity and as the international community prepares for designing its successor, the pressure on the poorer nations to make commitments for cutting down on their carbon dioxide emissions (i.e., fossil energy use) is inexorably building up. This pressure is particularly heavy on China, India, Brazil, Russia, South Africa and other large "emerging economies". Again, as at Kyoto in 1995, there appears to be little meeting ground for the different players. The developing countries emphasize that they are the victims, not the perpetrators of the huge historical emissions whose residues form the stock of greenhouse gases in the earth's atmosphere; that their emissions may be significant and growing, but so are their populations – which means that per capita they are still below the industrialised countries by orders of magnitude; and by any standard of fairness it is the developed countries that have to take the primary responsibility for cutting down on global carbon dioxide emissions. The industrialised countries claim that without some reduction in the emissions from emerging economies, global change cannot be contained within the desired limits.

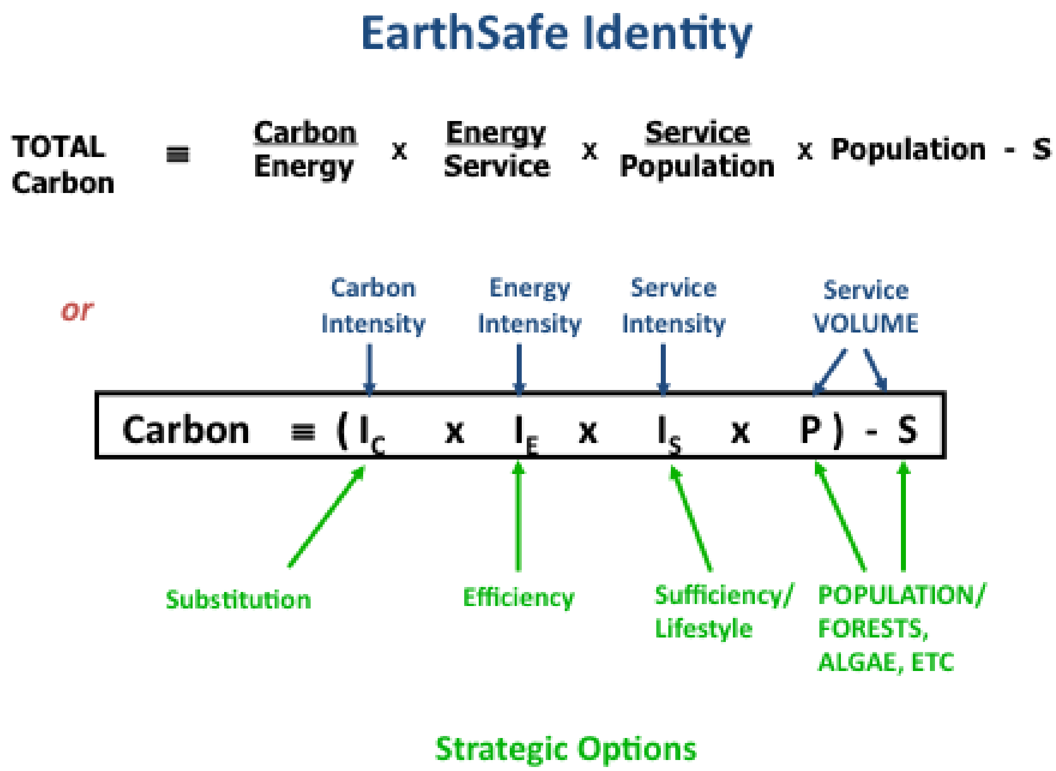
This paper suggests that one common platform that would attract and bring together almost all parties is the growing recognition that the global economy, particularly in terms of its consumption patterns and production systems, and the global population, in terms of its numbers and growth trends are now out of balance with the limits of the global resource base. There are, of course, a few states today, mainly in Europe and East Asia, whose economic and demographic situation encourages them to promote pro-natalist policies – but very few people hold the view that the world as a whole can support more people at standards of living that everyone now aspires to. The global economy, with an ecological footprint approaching 1.4[3], is already using 40% more resources than the Earth produces and it is difficult to see how this can be sustained for long.

People, Resources and the Environment

Starting with Paul Ehrlich's simple Identity, which relates environmental impact (I) to Technological efficiency (T), per capita use of resources (Affluence) and population (P), and relating impact with people and their lifestyles[4], (which has evolved to $I = P \times A \times T$). Subsequent variants have included the King identity, the Kaya Identity and the Schellnhuber Identity, as quoted in Schellnhuber 2008. To focus more closely on the impacts of factors that have been largely neglected in past analyses such as population and sequestration of greenhouse gases, the Identity would now need to be expanded to:

[3] Global Footprint Network

[4] Ehrlich, P. R. & Ehrlich, A. H. 1990 "The Population Explosion"



Much of the research, literature, policy studies and international dialogue thus far have addressed Carbon Intensity and Energy Intensity issues, which largely lend themselves to technological solutions and market-based action. Governments, business and academia have focused primarily on these kinds of initiatives. Carbon intensity is amenable to substitution by “cleaner” energy sources, such as solar, wind, biomass and many other renewable fuels, as well as conservation and demand side management. Lowering energy intensity is achievable primarily by increasing the efficiency of our technologies and production systems, primarily by miniaturisation, time-sharing and various other measures to reduce bottlenecks and waste and to raise performance.

Lowering the Service Intensity, which requires changes in lifestyles and consumption patterns, has been flagged primarily by civil society and individuals with a social philosophy orientation, for whom today’s way of life is out of balance with the limits of nature. Lacking quantitative analysis or enthusiastic support from the dominant sectors of society such as government, business or the media, these issues have not yet penetrated deeply into the official international dialogue on climate change.

While the role of carbon sequestration, by forests, algae, soils and other natural agents, is widely understood and accepted as a desirable goal, it too has not yet become a legitimised instrument for mitigating climate change. Despite strong campaigns for including REDD and REDD+ initiatives in any post-Kyoto regime, the likelihood of such options being adopted is still somewhat remote.

The one factor that does not seem to be on the table at all is Population. Virtually none of the literature or negotiations mentions the role of population as relevant to global efforts to reduce carbon emissions or to mitigate climate change in any way. The taboo on this subject seems to be deep and close to complete. The only mention of population in mainstream discussions is the assumption that the number of people on Earth in 2050 – or 2100 – will be "X Billion" where X is a large number usually taken from the medium population projections of the United Nations Population Fund. The general assumption appears to be that the population in 2050 will be about 10 Billion and so the carbon emissions will be commensurately high.

Hypothesis and Caveats

There appear to be considerable opportunities for reduction of carbon emissions through accelerated development, which generally leads to the reduction of desired human fertility; and, moreover, there are a variety of very low cost interventions that can speed up both processes. Since birth rates in the developed countries are already low, and in some cases even below replacement levels, this approach applies primarily to the developing countries, where the future impact on resources and climate due to population growth would be severe.

The advantage of this is that the poor countries can, by adopting the measures described here, take their rightful place in the climate change negotiations as contributors of effective solutions rather than simply as deniers of current of future responsibility. Moreover, they can legitimately demand financial and other compensation for future emissions saved.

For the rich countries, the value of slowing down global population growth is extremely high, since it is the only way they can hope that future global emissions will be limited by all and thus lead to permissible limits on greenhouse gas concentrations in the atmosphere in the long run.

But it should be clear that these solutions based on lowering population growth cannot, at best, reduce carbon emissions by more than 25 to 30% of the reduction that needs to be achieved if the global climate is to be stabilized at a reasonable level. In the language of "wedges"[5], it can only account for one or at most two of the seven wedges needed.

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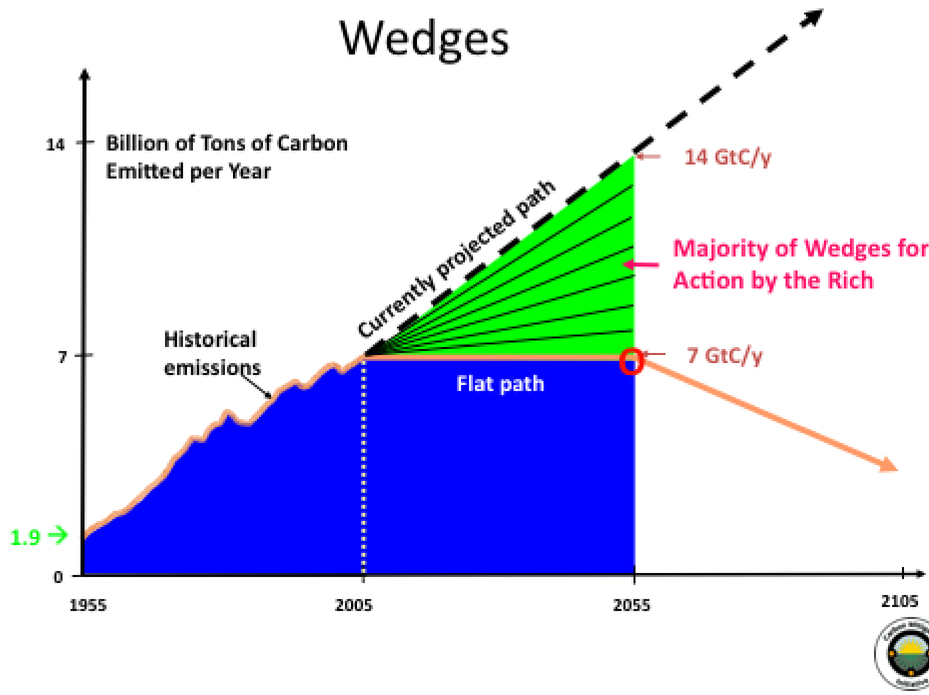
[5] Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies S. Pacala and R. Socolow



The bulk of the carbon emission reduction will have to be achieved by and within the global North on account of historical responsibility, resilience to climate change built up through prior use of fossil fuels and existing financial capability. There is no viable substitute on the horizon for the action that industrialised countries must take to reduce their greenhouse gas emissions.

Secondly, in proposing the approach below, it is not the intention of the authors to suggest that improvements in the lives of the poor, the women and the marginalized in the developing countries is needed only for what they can do to mitigate climate change*. The poor, the women and the marginalized have an intrinsic right to live better, longer and more fulfilling lives. This is a moral imperative, as well as an ecological one. While education of boys is certainly important, the emphasis here on girls' education is simply in recognition of the imbalances that exist between the genders and of the need to empower and build the confidence and capability of those, often girls, who have little say in the choices that most affect their lives. Rapid social change needs rapid improvement in the ability of all to exercise their rights and entitlements.*

The case made in this paper is that international development efforts can and must be reoriented so as to solve both issues at the same time: *bringing about an equitable, fair and widely shared improvement in the lives of people and by doing so, to achieve demographic outcomes that also serve to mitigate climate change.*

It is also our view that any opportunity that creates a “positive sum”, win-win situation, however small, can act as an effective common ground to enable the different sides to enter constructive dialogues that can take them beyond the initial impasse.

New Versions of Old Insights

As far back as 1965, Professor Roger Revelle, who incidentally in an earlier career as an eminent oceanographer first commissioned the studies that discovered the rising levels of CO_2 in the atmosphere[6], had recognized that population growth is not an exogenous parameter, but that it is heavily influenced by social and economic factors; policy decisions can have deep impacts on fertility, mortality, migration and other demographic variables[7]. It was his firm understanding of the demographic transition process, as it is for the authors of this paper, that population growth is no less a result of per capita GDP than it is a determinant of it. Birth rates, in a particular society, are highly correlated with the general wellbeing people feel in that society, with their aspirations and expectations for the future and with the position of women in it.

An equitable, widely shared improvement in the lives of the people is a sure route to smaller families. One way to accelerate or short-circuit this process is to make direct investments in interventions that improve the quality of life of the poor. As the UN Conference on Population in Cairo, 1995 clearly concluded, such interventions include education for girls, livelihoods and jobs for women, effective and access to female reproductive health services and similar gender empowerment measures. Other strong determinants of human fertility have long been known to include measures to reduce infant mortality and policies for old age security. It is also widely agreed that availability of electricity, light and sources of domestic or community entertainment such as television provide inexpensive distractions that can help occupy the time families spend together.

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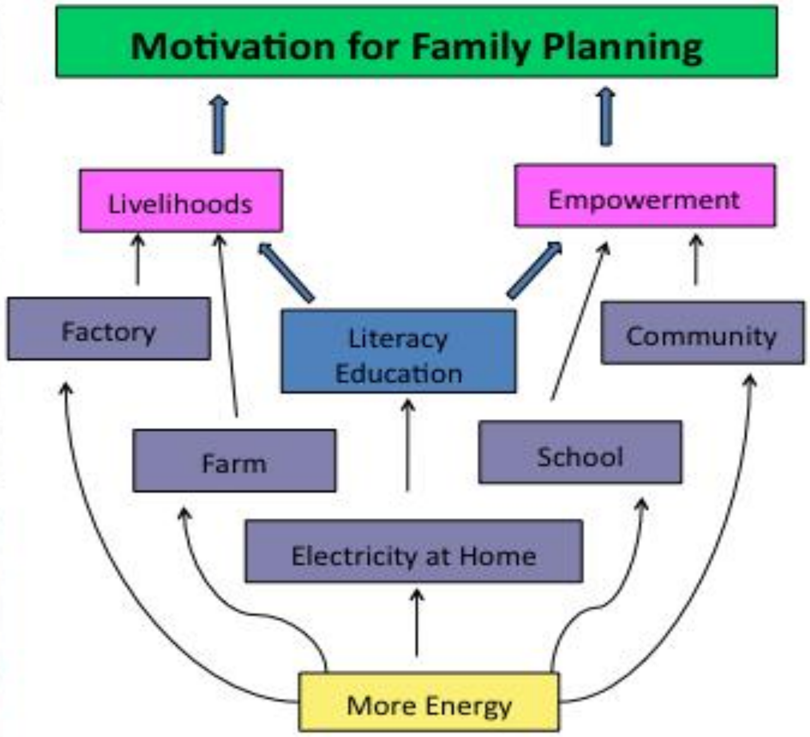
[6] Revelle, R., and H. Suess, "Carbon dioxide exchange between atmosphere and ocean and the question of an increase of atmospheric CO_2 during the past decades." Tellus 9, 18-27 (1957).

[7] Revelle, R, “Can Man Domesticate Himself?”, Bulletin of the Atomic Scientists Vol.XXII, No.2 , February 1966.



Though there may or may not be a direct causal link between improving quality of life and reducing desired total fertility, it is possible to show that with an increase in income (or energy, or any co-variant of per capita quality of life) the poor will be able to make better use of existing resources and of their time[8]. For example, an increase in income means that a poor family would be able to send its children to school and provide lights at home for them to study by. Similarly, they would be able to make use of more efficient technologies at home or in the field and would also be able to gain better access to health services.

It should therefore be possible for developing economies to reduce birth rates, and thus population growth rates by any number of means – accelerating the delivery of services associated with development so that everyone is better off to an extent that they wish to have small families. In the case of Sri Lanka, the southern state of Kerala in India, and more recently Thailand, Korea, and the other states of Southern India (Tamil Nadu, Andhra Pradesh and Karnataka), various welfare measures enabled the respective States to simulate some of the conditions that exist in a developed country and thus engendered the feeling of wellbeing and hope for the future that leads to a desire for smaller families. In the brief period of a decade or two, these economies were able to make it through the democratic transition to a condition of almost replacement level

[8] Over the past 27 years, Development Alternatives has created millions of livelihoods in impoverished areas across India, most of these initiatives have focused on women – the quality of life and subsequent drop in fertility of these regions has been drastic. Data on fertility, quality of life indicators is available on request.

fertility – and as a result to accelerate real and sustained development for their people as well.

Regions such as Sri Lanka, or parts of South India, which have successfully lowered the rates of their population growth by focusing on improving quality of life, should be able to claim credit for the significant contribution they are making to reduction of greenhouse gas emissions.

The Model

The correlation between fertility and various parameters that represent human wellbeing is starkly apparent from both the historical trajectory of fertility in countries that have traversed the demographic transition and comparison of the current data of all countries. Figure A shows the relationship between fertility and per capita GDP.

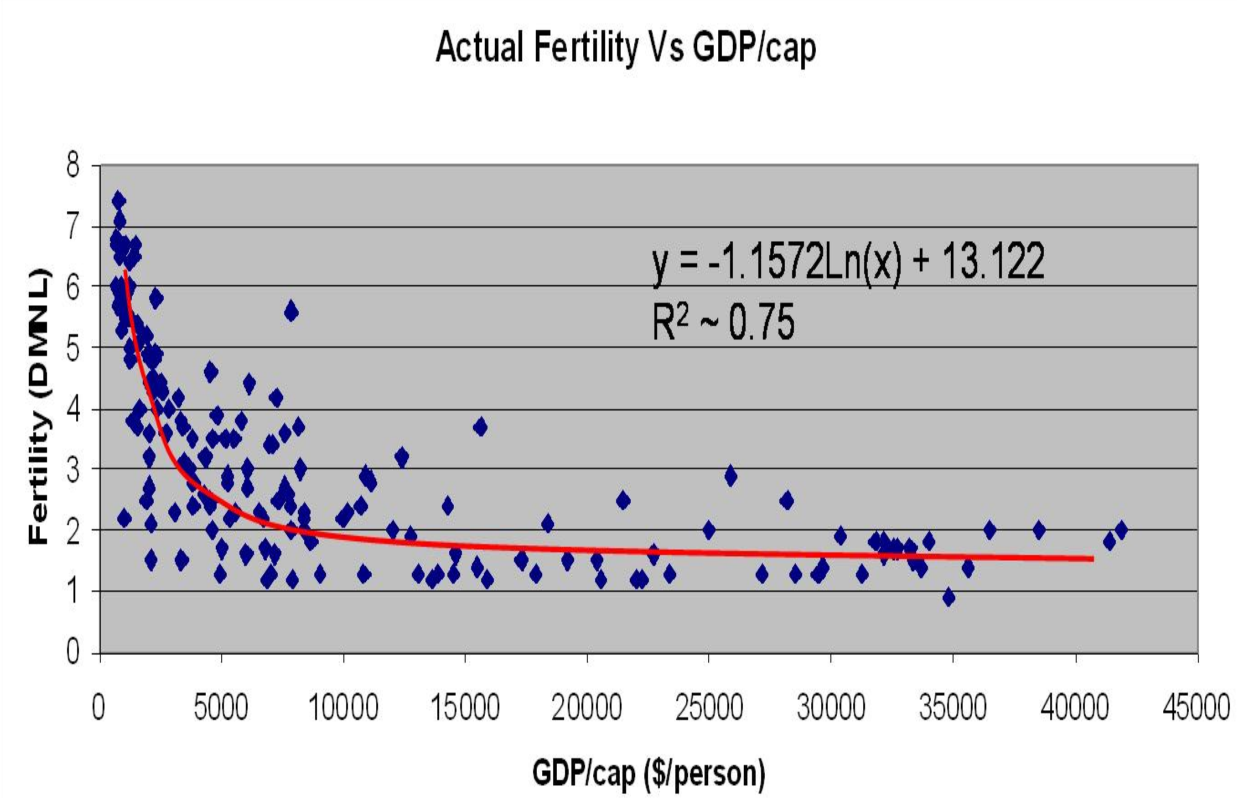


Figure A: A plot of fertility (No. of Children per Woman) vs per capita Income for all countries except OPEC members. Data from the UNDP Human Development Report (http://www.hdr.undp.org)

The maps in Figure B show similar relationships for fertility with other social welfare indicators such as enrolment of girls in schools, women's employment, etc.

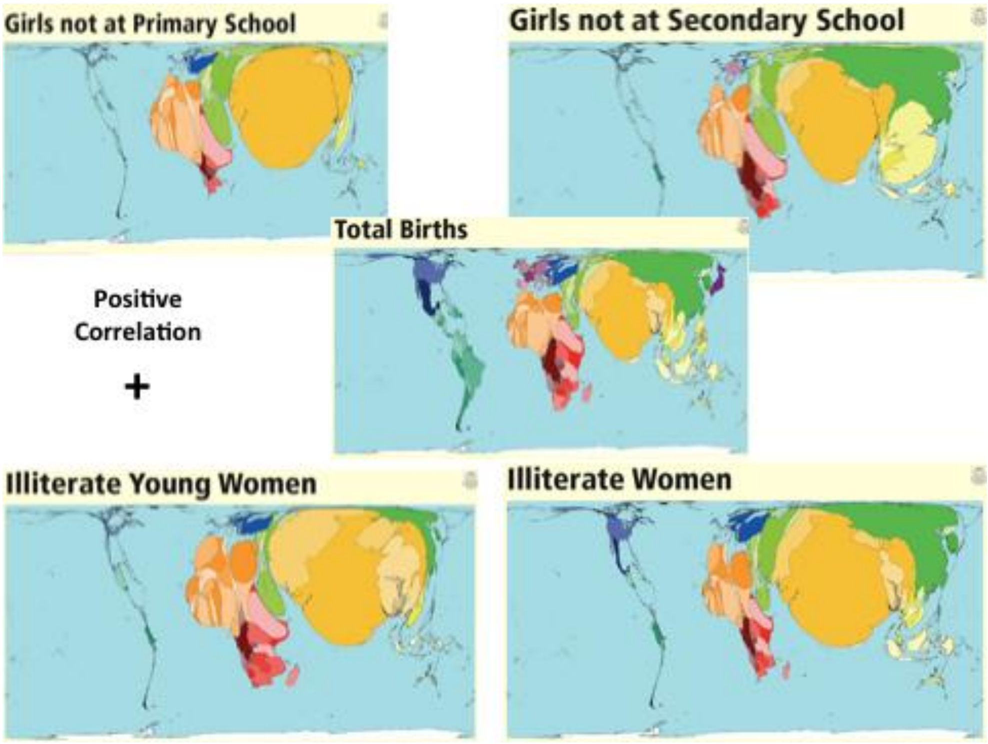


Figure B: Parametric maps showing various gender imbalances worldwide. (© Copyright 2006 SASI Group (University of Sheffield) and Mark Newman (University of Michigan).)

Figure C shows that the demographic conditions in a country such as Viet Nam (Fertility: 5 children per woman and Energy use: 500 Kg of Oil Equivalent per person per year) can easily be changed to a fertility of 2 children per woman with the addition of 1,000 KgOE/yr – bringing its family size close to that of Thailand today. An even simpler and less expensive method would be to provide the gender empowerment facilities identified by the Cairo Conference.

The cost of interventions such as creating schools for educating girls and enterprises for employing women has been estimated from actual field data. Our estimate for educating a girl to a level where she has options other than bearing children is approximately $ 2,000.

Energy Consumption and the Demographic Transition

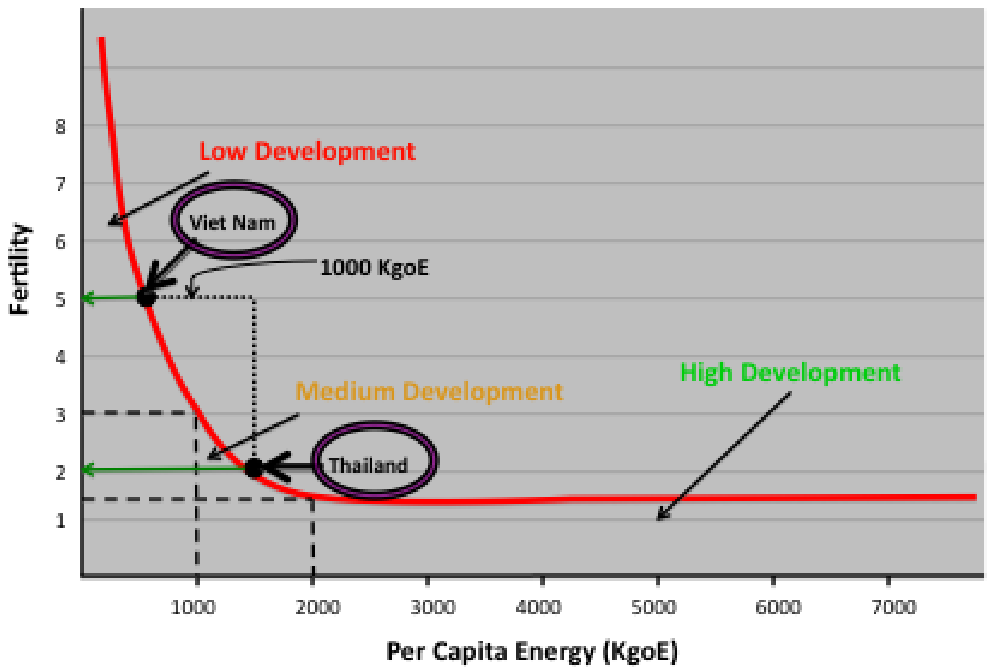
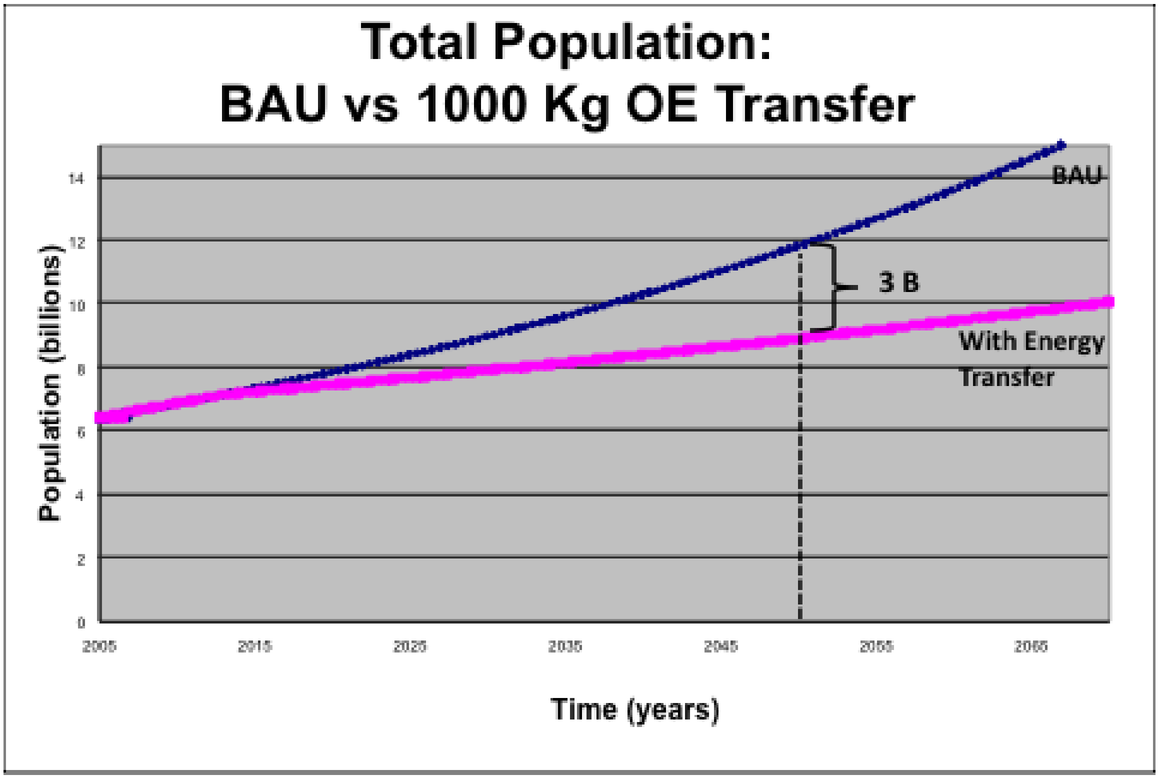


Figure C: A typical fertility transition curve.

Results

Running the model under different assumptions shows that it is possible to end up with a world population by the target dates (2050 or 2100) that would be well below the numbers that would exist if business were to continue as usual.

Using plausible assumptions on redirecting investments towards gender empowerment and other interventions in the poorer regions of the world, it is possible to imagine a world in 2100 that would have several billion fewer people than is generally assumed today. By 2050, it is possible to redirect global development efforts to save as many as 2 Billion births.



Today's average emission of CO2 stands at roughly 2 tonnes per capita. Assuming that each of the persons not born would have been responsible for 1 tonne of CO2 emission per year, and that he or she would have lived to an average age of 60 years, the total saving per person would be 120 tonnes of CO2. At a value of $ 15 per tonne, this is close to $ 2,000 – more or less equal to the investment made in her education.

If we include the savings due to averting the births of her children and grandchildren up to the end of the target date, the investment actually yields very high returns indeed.

In comparison with many of the other solutions currently under consideration, this is an extremely low cost method to reduce carbon emissions. In a 50-year simulation, the model puts the cost at around $ 10 to 20 per tonne of CO2 emission saved. With a 100 year time horizon, the costs actually come down to well below $ 10. The latest estimates for Carbon Capture and Storage come out to over $ 100 per tonne[9].

[9] MOHAMMED AL-JUAIED, ADAM WHITMORE, "Realistic Costs of Carbon Capture", Discussion Paper 2009-08, Energy Technology Innovation Policy Belfer Center for Science and International Affairs Harvard Kennedy School, Harvard University

The savings in CO_2 emission from this kind of approach could reach as much as 2 or more billion tonnes per year.

Relevance to Climate Mitigation

Activities that lead to reduced population growth, and as a consequence to lower emission of CO_2 should be just as eligible for recognition of their contribution directly to mitigation or indirectly as carbon-offsets as are normal engineering works that try to achieve the same results through improved efficiency. Measurement of demographic parameters is a well-known science and the number of births averted can be estimated quite accurately by measuring the difference between what would have been the population had business-as-usual trends continued and what was actually the case after the interventions.

The carbon savings achieved in this manner since, say, 1990 could be allotted to the account of the country as part of its direct contribution to mitigation; the carbon saving yet to come could be the source of CDM or other carbon offset money to be used directly for the kinds of activities described here. Conventionally, carbon offset money is paid after the offsetting activity has been completed, verified and approved. This convention could be changed to provide front-end capital for setting up schools, enterprises, etc – or alternatively the future expected revenue streams could be securitized into a bank loan, which would be repaid from the carbon offset earnings when they materialize.

To be eligible for carbon offset or mitigation benefits, projects have to pass the “additionality” test, which shows that the reduction in greenhouse gases it results in would not have taken place without the incentives provided by those benefits. Given the time it takes for societies to move through the demographic transition and the well-known barriers they normally face in this process, fertility reduction resulting from female empowerment certainly meets the additionality requirements. In fact, given its inherent grounding in the behaviour of the family and community, it should be taken as an archetypal gold standard mitigation action.

Conclusion

The model, based on System Dynamics methods, shows that there is a strong prima facie case for redirecting international development efforts towards eradicating poverty and particularly at improving the lives of women in developing countries. Preliminary calculations show that $ 1 spent on such programmes would yield more carbon emission reduction than $ 10 spent of engineering solutions such as Carbon Capture and Storage.

Needless to say, improving the lives of the poor, and particularly the women and children living in extreme poverty, is an imperative in its own right, and from many viewpoints – the moral, the ethical, the social, the ecological and the practical. It is also one of the least cost ways of achieving goals that currently can capture the support of global decision-makers. The argument presented in this paper, based on a quantitative analysis of the relationship between human fertility and specific development interventions that emphasize gender empowerment, shows that rapid, equitable development is also crucial to reduce carbon emissions, stabilize the climate, reduce the pressures of humankind on nature and its resources, and save life on Earth.

The systemic analysis summarized above shows that there exists a possible win-win strategy that can bring the competitors in the current game to play to agreed, logic-based and consistent rules. These rules would be designed to overcome the consumption-population related stand-offs that exist today.

The analysis shows conclusively that, counterintuitive and paradoxical though it might appear, accelerating the removal of poverty throughout the world, involving access by the poor to higher energy services, not lower, provides the surest and least cost transition path to mitigating climate change. Depriving the poor of a better life can only be severely counterproductive for achieving climate mitigation goals.

Annex: The Model

Introduction

In a world of growing complexity, often neither the lessons of history nor “common sense” is adequate to help us understand the causes and effects that determine the outcomes of human interventions. Systems Thinking is a scientific art that facilitates rational analysis and clarity of understanding that permits us to make better decisions.

The more specific science of System Dynamics offers a powerful method to characterize the functions and behaviour of real world structures. The work of Jay Forrester, father of System Dynamics[10] demonstrated the value of this method in applications as varied as complex urban communities, multi-faceted industries and global societies. World3, the original global dynamics model, (further refined by Meadows et al.[11]) shows the growth of economy and population in a world constrained by resources and pollution. The methodology has since been refined through several generations of elaboration, testing and application.

The world today is beset by many successive socio-economic structural failures and concurrent crises. Of these, perhaps the most pressing one is that of climate change, recognized widely to be the result of increased levels of greenhouse gases in the atmosphere, which in turn result from anthropogenic emissions of these gases, primarily from the burning of fossil fuels. The final result is that these changes in the climate now threaten to destroy our life support systems. The solutions discussed thus far have been largely limited to technological improvements and lifestyle changes. Very little attention has been given to the effects of population growth.

The EarthSafe Model, Ver 1.3

Objective: *CO2 emissions are an indicator of our planet’s poor health. This model seeks to quantify the effect of population dynamics on the amount of CO2 released annually into the atmosphere and improve the quality of life of those living in its poorest regions. .*

Version 1.3 of the EarthSafe model represents a world comprising 4 Regions defined economically rather than geographically (Very Poor, Poor, Medium and Rich countries). Each region is further divided into 3 classes: those who live in the poorest (L Class), middle (M Class) and rich (U class) income groups, as determined by data.

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[10] Jay Wright Forrester, “Industrial Dynamics” (1961) “Principles of Systems” (1968)

[11] Dennis L. Meadows, Donella H. Meadows, Jorgen Randers, William W. Behrens, “The Limits to growth: A report for the Club of Rome's Project on the Predicament of Mankind” (1972)

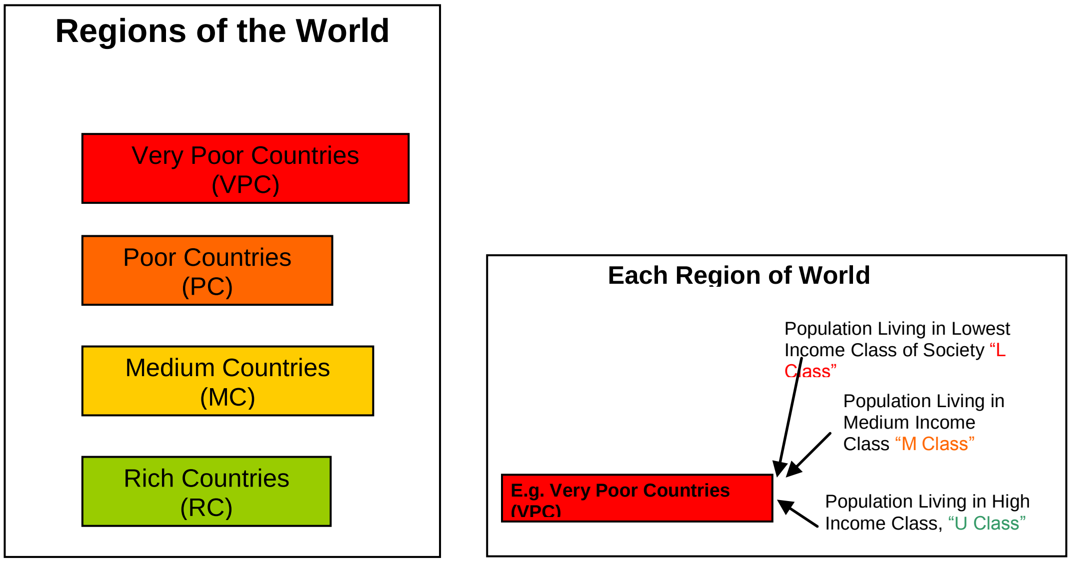


Figure 1

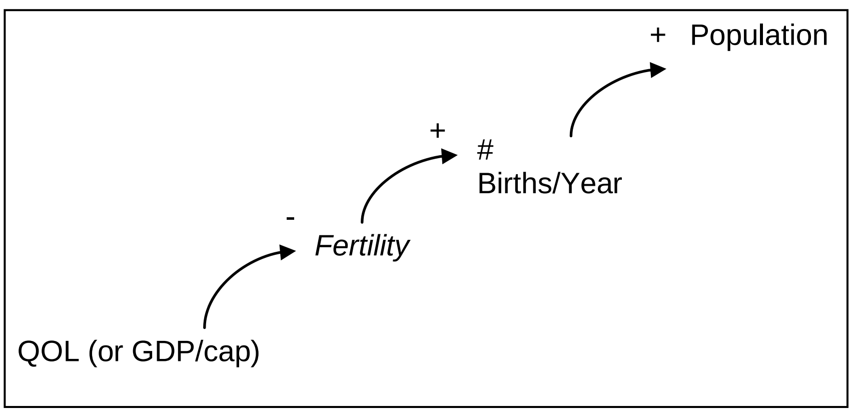


Figure 2 Causal relationship between quality of life and population growth

For a first approximation, as in most standard Economics texts, and without loss of relevance to real world behaviour where environmental carrying capacity poses no constraints parameters such as food, water, land or pollution have been omitted. Resource consumption, however, is fundamental to our model as is the relationship between population growth and quality of life – factors that are introduced in later versions of the EarthSafe model.

What Determines Population Dynamics?

Data from the UNDP Human Development Report and the World Bank Database, showed clear relationships between population growth and various indicators of quality of life; Figure 2 demonstrates, for example, the strong correlation between total fertility (number of children per woman) and per capita GDP.

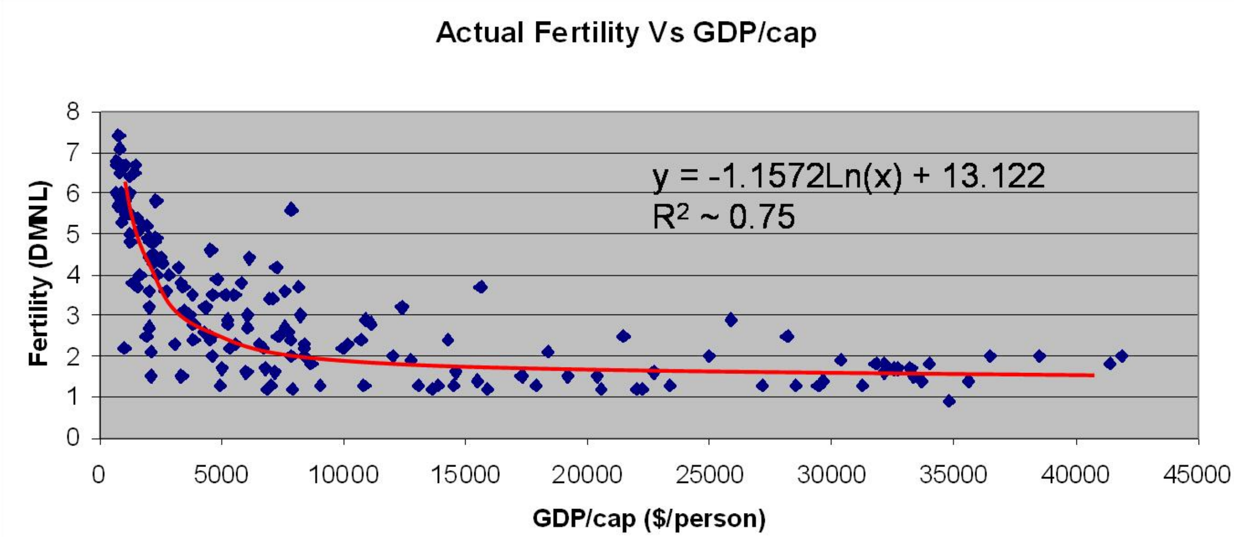


Figure 3 (representation of best fit trend line)
Data from UNDP/HDR and WDR. All countries included, except OPEC

Historically, under normal economic circumstances, the drop in total fertility has invariably followed the rise in per capita GDP. It is not unreasonable, therefore, to infer that the changes in per capita GDP are driving the changes in fertility. Moreover, the data show that the curve of total fertility vs GDP is very steep at low per capita GDP and flat at high per capita GDP. This means that even small changes in GDP at the lower end can lead to very high changes in fertility.

The model incorporates the normal growth expected in per capita GDP, which generally leads to a gradually declining fertility, as has been observed in all regions of the world in the recent past.

To accelerate the fall in total fertility directly, it is possible to further increase the GDP growth, either through policies designed to prioritize expenditures on industrialisation, agriculture, etc, or with external funds mobilized for this purpose.

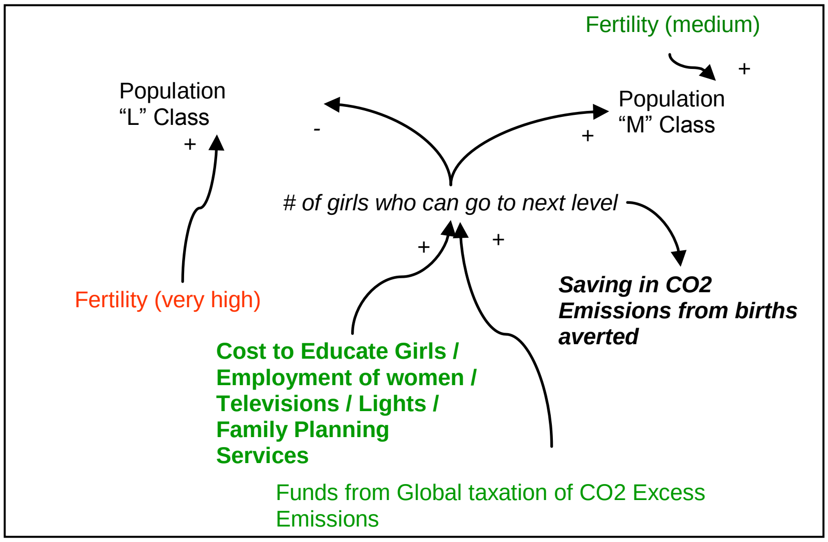


Figure 4 Interaction between lower and medium income classes in a region

Low Cost Intervention

Analysis of data shows that population growth is significantly higher in regions of low economic development. Accelerated population growth is the result of contributing factors such as the effect of perceived mortality on total fertility; for example, if a family believes that two out every four children born will die as infants, the family will have more children to compensate[12].

Verion 1.3 of the EarthSafe model will focus on the interaction between two classes of each region; Figure 4 represents the "L class" and "M Class" of each region; M Class, has higher per capita GDP and lower total fertility relative to L Class.

It is also possible to achieve the goal of fertility reduction indirectly by enabling young women in the L Class to achieve a better quality of life through, for example,

- Schools for education and vocational training of girls
- Enterprises for employment of young women
- Improved reproductive and health care facilities
- Electricity for domestic lighting and television
- Etc

Such interventions can, at very low cost, help the movement of people from the L (high fertility) class to the M (lower fertility) class (Figure 4).

The cost of any of these interventions and the funds available for them determine the number of girls who can participate in any region. Experience shows that

[12] "Dynamics of Growth in a Finite World", by Dennis L. Meadows (Author), William W., III Behrens (Contributor) discusses, in detail, the principle of compensatory births and the effects of perceived mortality.

such costs can be quite low, enabling large numbers of people to cross the demographic transition in a short period of time.

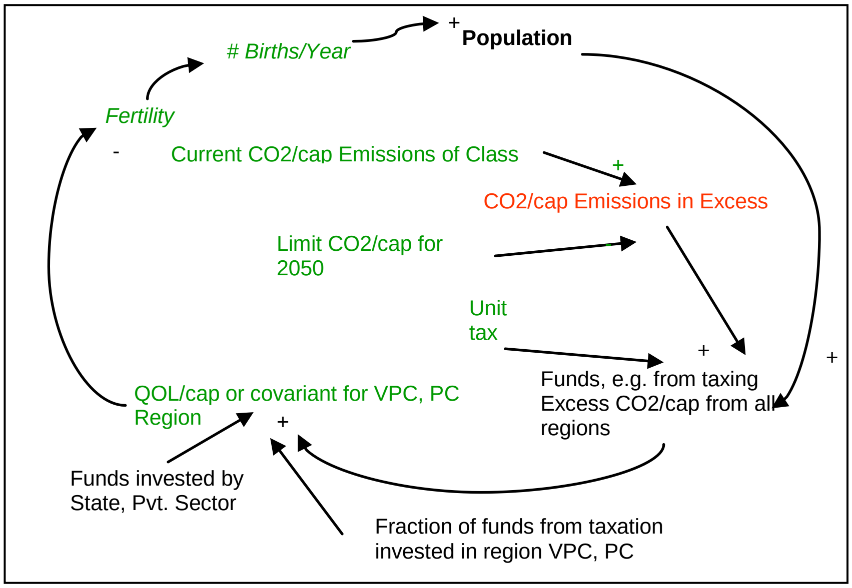


Figure 5 Overall feedback structure of model

Financing Fertility-Reducing Interventions

One possible policy by which funds can be raised for low cost intervention methods would involve taxing regions whose per capita CO2 emissions (*metric tons per person per year*) are above the critical threshold level and then redistribute these funds to poorer regions (Figure 5).

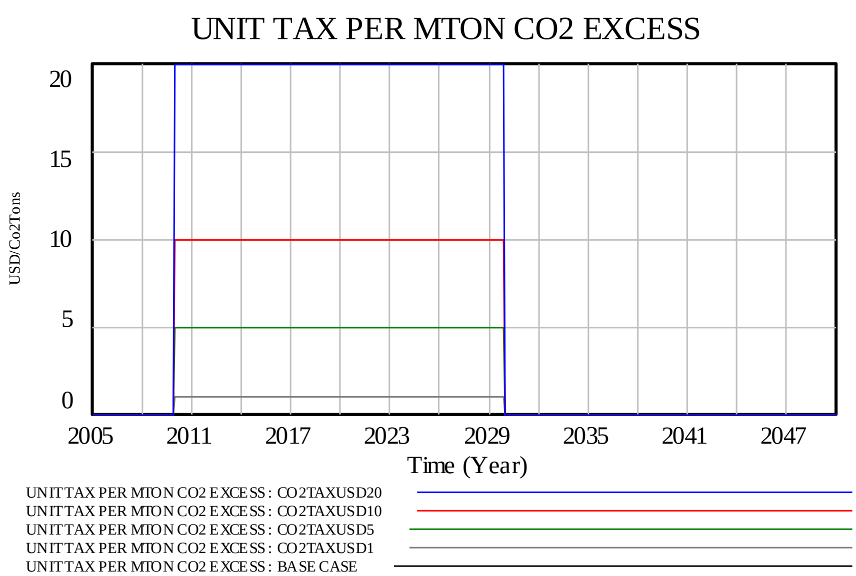


Figure 6

The critical per capita CO2 emissions for 2050 are calculated by examining the relationship between these emissions and the concentration of CO2 that remains in the atmosphere, and relating this concentration to the desired atmospheric temperature rise in 2050.

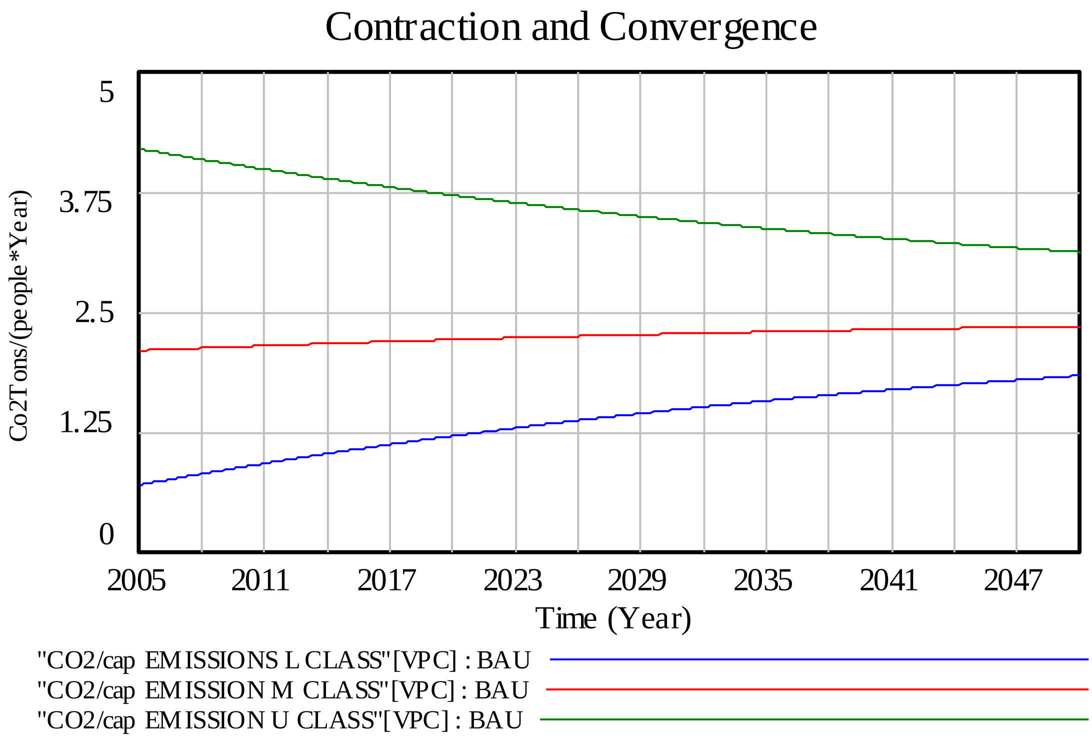


Figure 7 Per Capita CO2 Emissions for the three classes in the very poor region

Contraction and Convergence: Due to historical responsibilities and technological capacities, classes with high per capita CO2 emissions will reduce their levels of pollution, whereas classes with low emissions will, over time and with access to newer technologies, asymptotically increase their emissions to the level that is acceptable. The model achieves this phenomenon through a first order goal-seeking adjustment.

To calculate total CO2 savings, an analytical method has been developed to estimate future births averted from such interventions. For each girl who makes the transition from L Class to M Class, it is possible to calculate the number of births that did not take place because of the reduction in her desired total fertility, which resulted from the intervention. This figure allows us to calculate the cumulative CO2 emissions averted; the ratio of the cumulative costs of this policy, to the CO2 emissions averted, gives us the cost of abatement per ton of CO2.

In this version of the model, the key determinant for fund raising is the unit penalty (tax) charged per excess CO2 ton of emissions. Other assumptions are:

TABLE 1: Initial Conditions[13]

	VPC	PC	MC	RC
L Class CO2/cap (metric tons) Emissions	0.7	1.4	4.2	5.6
M Class CO2/cap Emissions	2.1	3.5	5.6	9
U Class CO2/cap Emissions	4.2	5.6	9	13
L GDP/cap (USD/person)	1000	2500	8000	10000
M GDP/cap (USD/person)	5000	7000	15000	25000
U GDP/cap (USD/person)	15000	20000	40000	100000
L Class Death Fraction (people/people/year)	0.014	0.014	0.013	0.012
M Class Death Fraction (people/people/year	0.013	0.012	0.011	0.011
U Class Death Fraction (people/people/year	0.010	0.010	0.010	0.010

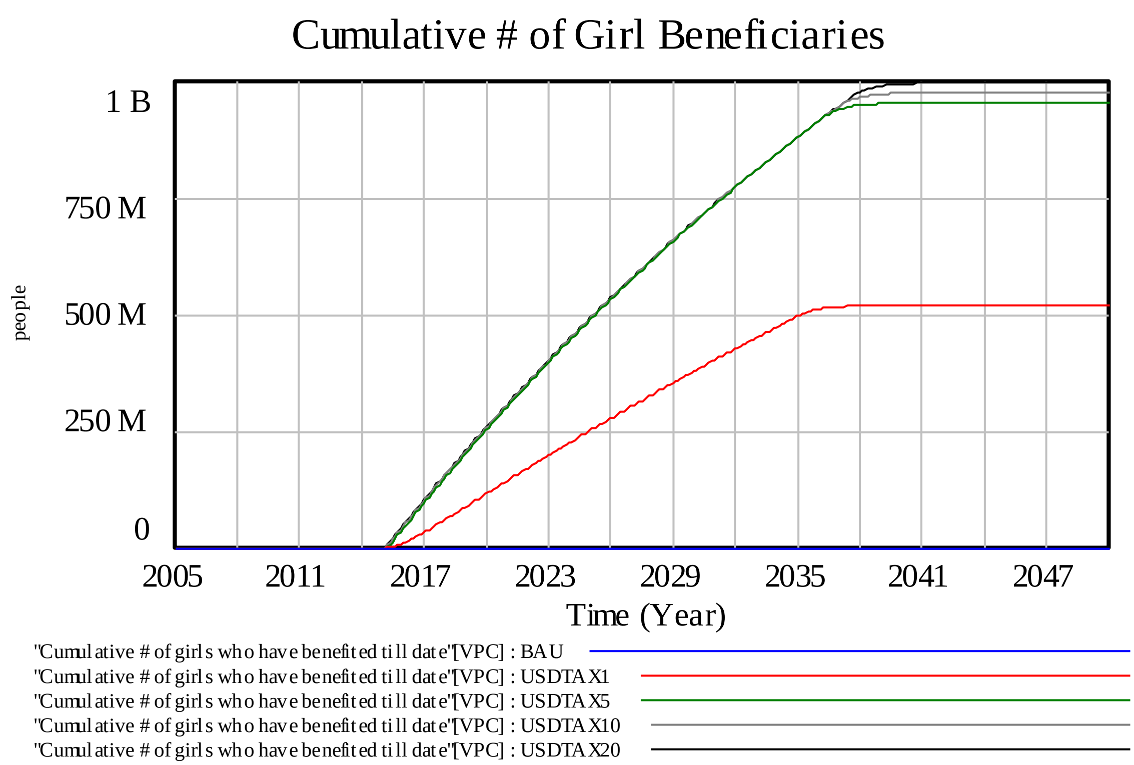
- Initial Global Population, ~ 6 Billion People
- Per Capita GDP growth rate 1% for L Class, 3% for U Class
- ~ 30% of population is female of reproductive age for each class, each region
- Funds distributed: 67% to VPC Region, 33% to PC Region
- Reasonable values for Unit tax, from USD 1/MtonCO2 to USD 20/MtonCO2
- Number of girls who can benefit from the program is limited by the minimum time needed to educate girls and cost per girl
- Cost of educating for a girl, USD 2000/person
- Time to complete education, 5 Years

Table 2 Sample of results (Taxation Policy in effect from 2010-1030):

Variable	***Base Case (No tax)***	Tax (**lower limit**)*: USD1 / per capita excess Mtons CO2*	Tax*: USD5 / per capita excess Mtons CO2*	Tax*: USD10 / per capita excess Mtons CO2*
Global Population at 2050 *(**Billion** people) Figure 13*	12.48	12.09	11.6	10.84
Global Anthropogenic Co2 Emissions at **start** of model *(**Billion** Mtons of CO2/Year) Figure 9*	29.70	29.70	29.70	29.70
Global Anthropogenic Co2 Emissions at **end** of model *(**Billion** Mtons of CO2/Year) Figure 9*	35.96	35.68	35.14	35.13
Approx. Number of girl births averted at **end** of model [VPC] *(**Billion** people) Figure 8*	0	0.45	1.31	1.34

[13] Estimated from various data sets: UNDP HDR, World Bank, IEA

Cumulative Funds Raised for region [VPC] **over entire run** *(**Trillion** USD)*	0	1.15	5.9	10**
Cumulative Funds Spent on Educating Girls **over entire run** of model [VPC] *(**Trillion** USD)*	0	1.03	1.90	2**
Cumulative Funds available for other intervention methods **over entire run** of model [VPC] *(**Trillion** USD)*	0	0.12	4	8**
***** Average Funds Available per Year (Billions of USD/Year)	0	3	100	200
*** Cost of Abatement at end of 45 Year model [VPC] *(USD/MtonsCo2)* *Figure 10***	**0**	**14.27**	**14.27**	**14.27**
Cumulative CO2 Averted by **end** model (**Billion** *MtonsCo2 over 35 years)*	0	* 45.28	131.19	134.48
Percent of people living in L Class at **start** of model [VPC] *(DMNL) Figure 14*	*~ 60*	*~ 60*	*~ 60*	*~ 60*
Percent of people in L Class at **end** of model [VPC] *(DMNL) Figure 14*	78	64	29	28



***1:** Average funds available per year *(Trillion USD/Year)* =
[Cumulative Funds Raised for region [VPC] **over entire run** *(Trillion USD)* **-** Cumulative Funds Spent on Educating Girls at **over entire run** of model [VPC] *{Trillion USD}*]**/(**Final Time – Start Time of Policy**)***{Years}*

The difference between the "cumulative funds raised" and the "cumulative costs" involved in implementing low cost programmes gives as an idea of the amount of funds available for other intervention programmes to reduce CO2 emissions. Divide this figure by the time between the end of the model and the start of the intervention to get the *average* funds available per year for *other* programmes

***2:** In the 95 Year simulation, the cost of abatement is one fifth (~ USD 3) that of the 45 year run (~ USD 14); the number births averted is almost five times as much

***3:** 72.75 Billion MtonsCO2 Averted is equivalent to an average of 3.36 Billion MtonsCo2 Averted per Year (**for the 20 years that the policy is in effect**)

** Cumulative funds raised from taxing excess per capita CO2 emissions (**over entire run**), cannot reasonably exceed 10 trillion dollars, which is defined as the upper limit. Coupled with a maximum number of girls that can benefit from intervention, the upper limit for annual funds available for other methods cannot exceed 8 trillion dollars.

******* Please note that the figures in the table above represent **exponential** growth with no effect of feedback of capacity constraints

Figure 8

The figure above demonstrates the effect of various values of penalty tax on the number of possible girl births averted in Very Poor Countries. The policy is introduced in 2010 and lasts till 2030; after that there are no more girls to benefit. The interplay of declining fertility rates (due to increasing per capita GDP and proportionally adapting goals for desired fertility) reduces the cumulative number of girl births averted towards the end of the model run.

Note that girl births averted results in diminishing returns for penalties greater than USD 5/ Excess Mton CO2; if the total number of beneficiaries is greater than the maximum number of girls that can be educated by the system, the rate of outflow from one class to the next will be that of the maximum capacity of the system.

The analytical method for calculating approximate total number of girl births averted and CO2 savings: *PLEASE NOTETHE MESSAGE OF THIS PAPER IS TO IMPROVE QUALITY OF LIFE AND THUS REDUCE A POOR COMMUNITY'S **DESIRE** TO HAVE MORE CHILDREN*

First Generation of Births Averted = (Girl going to M Class) * (Current Difference in Fertility b/w both Classes) * (Average Number of girls born per woman) *{people}*

Current Difference in Fertility = (Current Fertility of L Class) – (Current Fertility of M Class) *{births/woman}*

Successive Births Averted = (First Generation of Girl Births Averted) * (Current Fertility of L Class) * (Average Number of girls born per woman) *{people}*

"N" Number of generations of births averted = (Time of Model Simulation) / (Average time for each generation to reproduce) *{dmnl}*

Average time for each generation to reproduce = 25 Years *{years}*

Total Number of Girl Births Averted by One Person= [First Generation Births Averted + (Successive Births Averted)^$^{(N-1)}$] * (Probability of Survival of Child) *{people}*

Cumulative Number of Births Averted = ∫ [(total beneficiaries each year) * (total births averted by one girl that year)] dt *{people}*
Integrated over model lifetime

Total Co2 Savings = Average Co2/cap Emissions * Cumulative Number of Births Averted
{Co2Tons} = *{Co2Tons/person}* * *{people}*

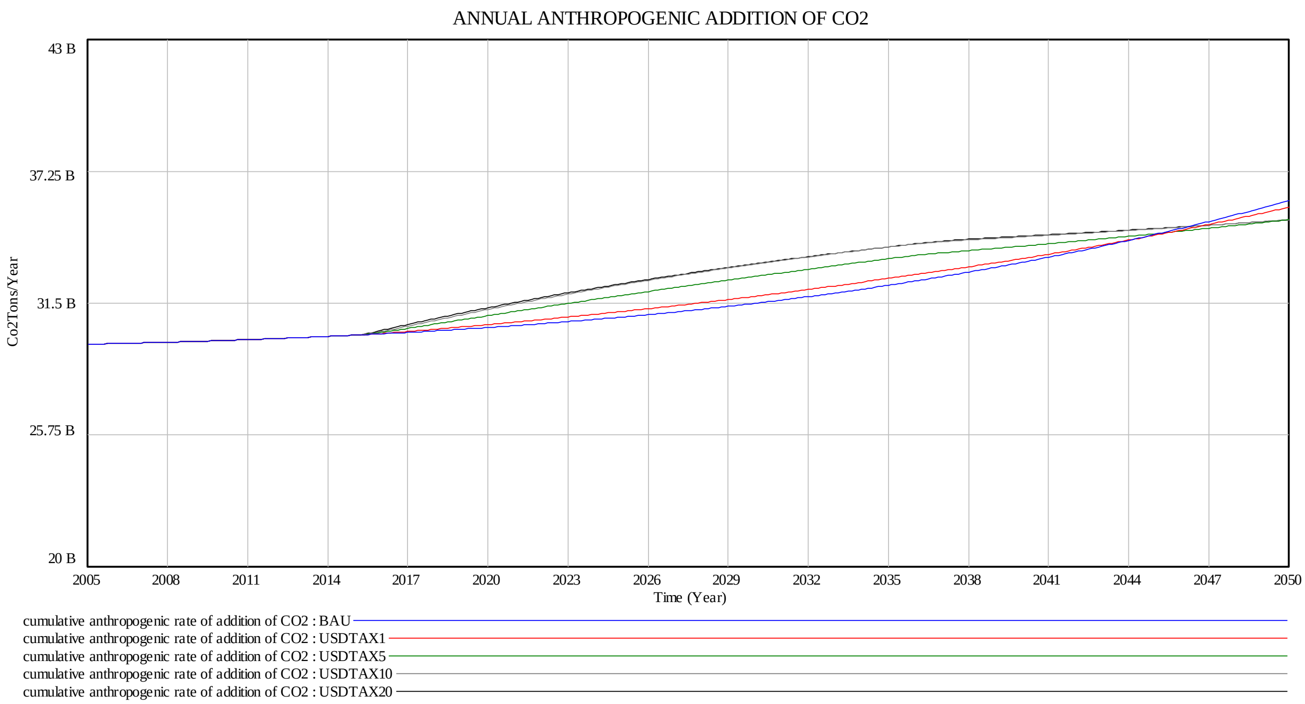


Figure 9

The behaviour of annual anthropogenic CO2 emissions over time is somewhat counter-intuitive (*Figure 9*); as the amount of the penalty increases, emissions initially increase relative to the base, but then start to decrease and eventually end up lower than BAU over the course of the simulation. The reason for the initial increase in emissions is that intervention takes people from a low income class (which has low CO2/cap emissions) to one which is higher (with higher CO2/cap emissions); however, simultaneously, per capita CO2 emissions for high income classes also approach the critical limit due to efficiencies – the net result is that cumulative CO2 emissions eventually drop below the business as usual case.

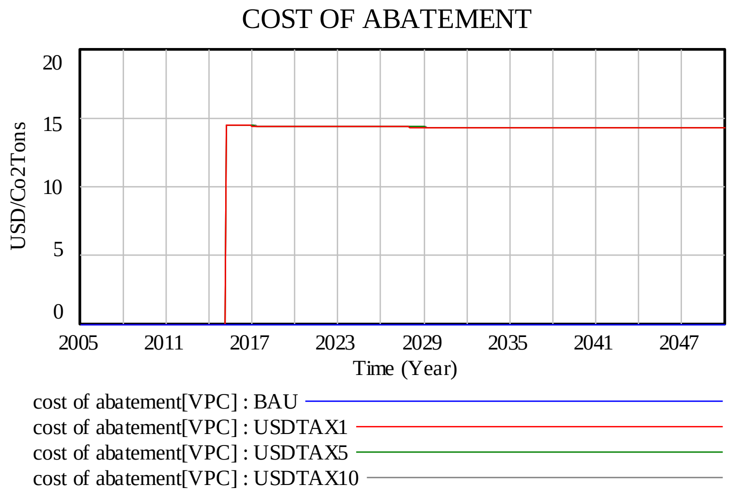


Figure 10 [50 Year Simulation]

When the policy comes into effect in 2010, the cost of abatement (in for example, Very Poor Countries) rises briefly to a maximum but settles at a low constant value after some time. The reason for the initial rise is that cumulative funds raised from taxation begin to increase immediately after the policy comes into effect, but there exists a delay due to the time it takes to educate a girl (five years for the first lot of girls to graduate). After the fifth year of introducing the policy, the ratio of cumulative funds to cumulative young women who have passed through the program (or CO2 averted) is constant.

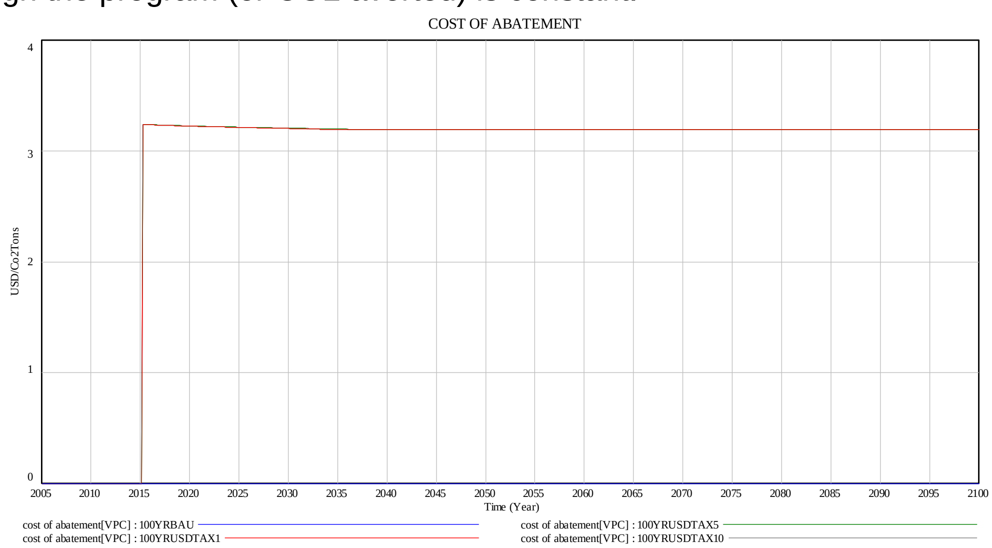


Figure 11 [100 Year Simulation]

As shown in figure 11, the longer the time for the simulation, the greater the number of births averted (see analytical solution above), which results in a lower average cost of abatement.

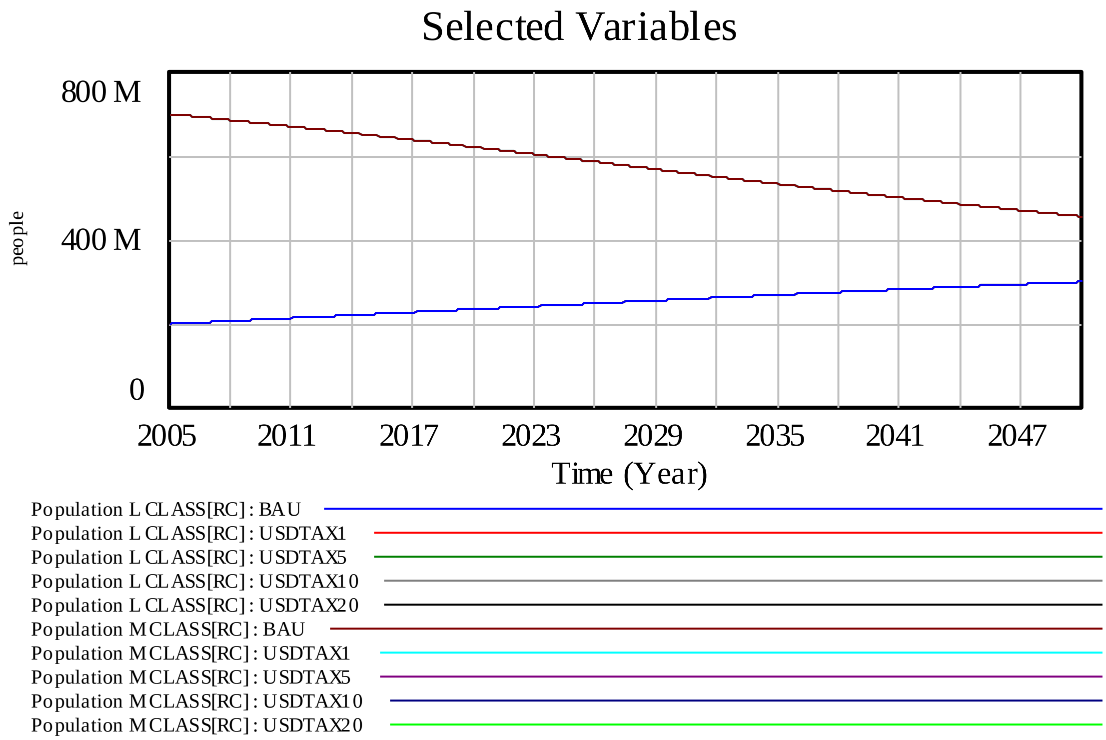
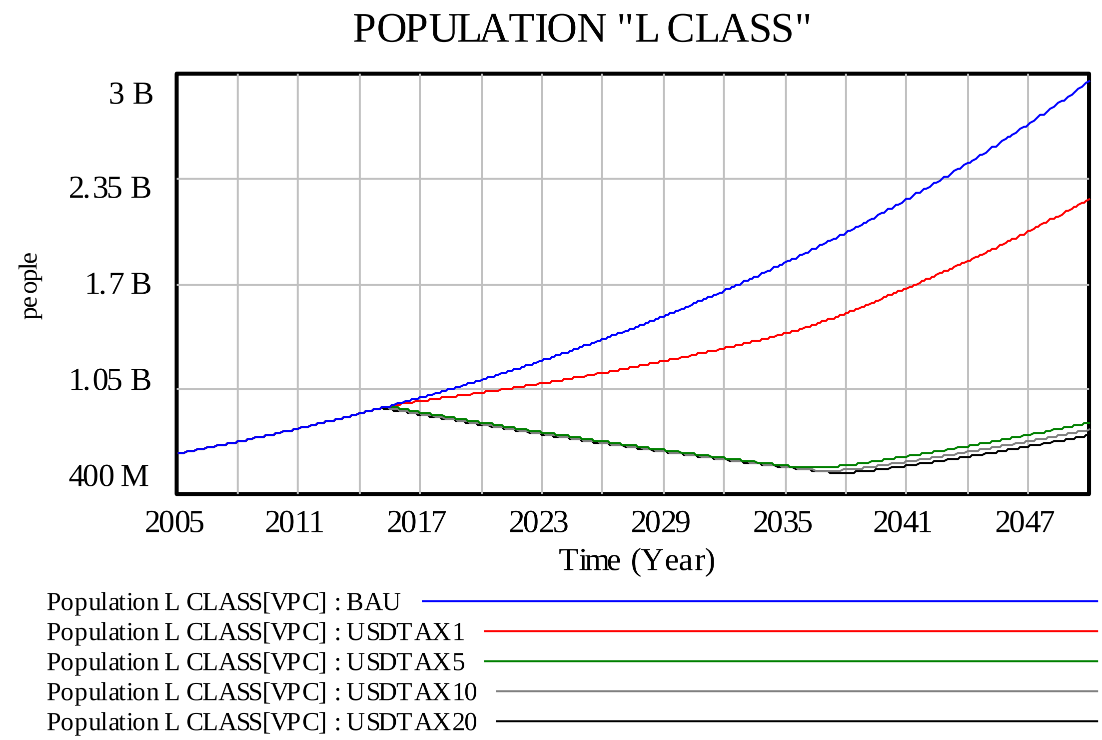
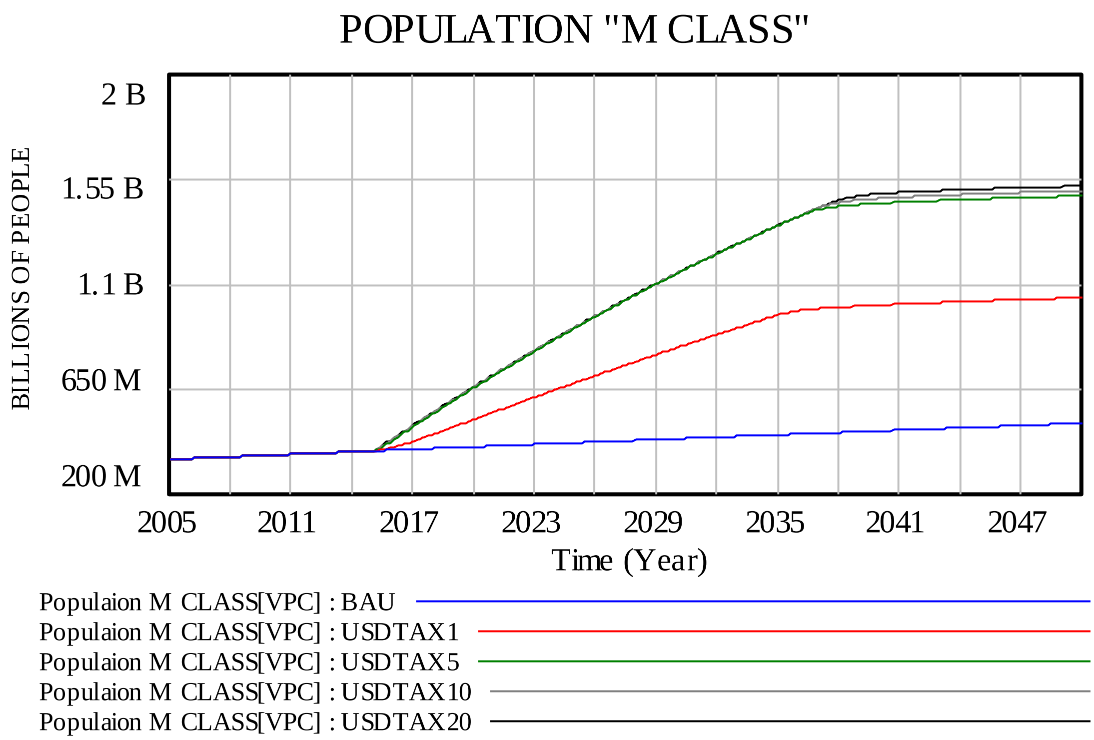


Figure 12

In this version of the model, the demographics of the rich regions (Figure 12, RCs and MCs) are not sensitive to the unit tax parameter; funds raised from taxing excess consumption are not re-invested in these regions (though in other versions of the model this does not have to be the case). The only factor which changes the fertility for this region is the growth of per capita GDP.



POPULATION "L CLASS"
3 B
2.35 B
1.7 B
1.05 B
400 M
people
2005
2011
2017
2023
2029
2035
2041
2047
Time (Year)
Population L CLASS[VPC] : BAU
Population L CLASS[VPC] : USDTAX1
Population L CLASS[VPC] : USDTAX5
Population L CLASS[VPC] : USDTAX10
Population L CLASS[VPC] : USDTAX20



POPULATION "M CLASS"
2 B
1.55 B
1.1 B
650 M
200 M
BILLIONS OF PEOPLE
2005
2011
2017
2023
2029
2035
2041
2047
Time (Year)
Populaion M CLASS[VPC] : BAU
Populaion M CLASS[VPC] : USDTAX1
Populaion M CLASS[VPC] : USDTAX5
Populaion M CLASS[VPC] : USDTAX10
Populaion M CLASS[VPC] : USDTAX20

Figure 13

The populations of the poor regions (Figure 13, VPCs and PCs) on the other hand, are very sensitive to the unit tax parameter. Depending on its value, the population living in L Class (below an acceptable quality of life) decreases quite dramatically during the implementation phase of the policy. As the policy comes into effect, it opens up the flow between the lower and middle classes thereby decreasing the number of people in the poorer segment and increasing those in the higher segment.   As the class of people with higher per capita GDP have lower fertility, their contribution to the cumulative growth of population is far less than that of the poorer class of the region and as a result, *global* population (Figure 14) decreases relative to the base case.

Furthermore, as seen in the following graph (Figure 15), the fraction of population living below an acceptable quality of life in the very poor region decreases quite significantly as a result of the policy.

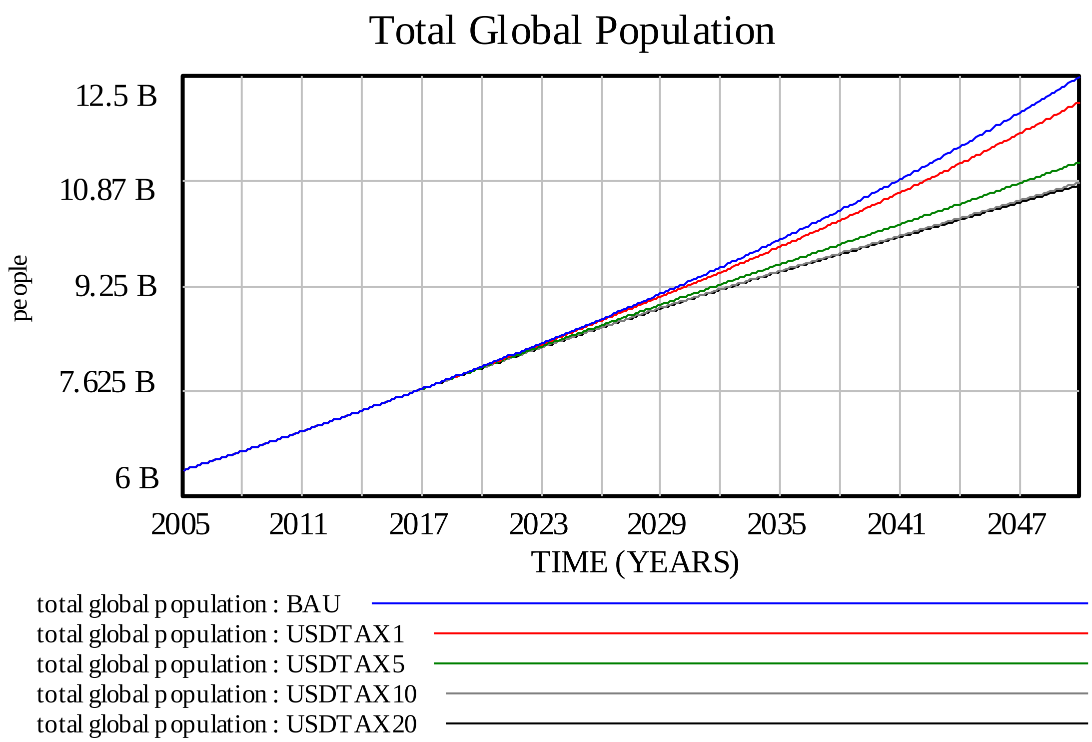


Figure 14

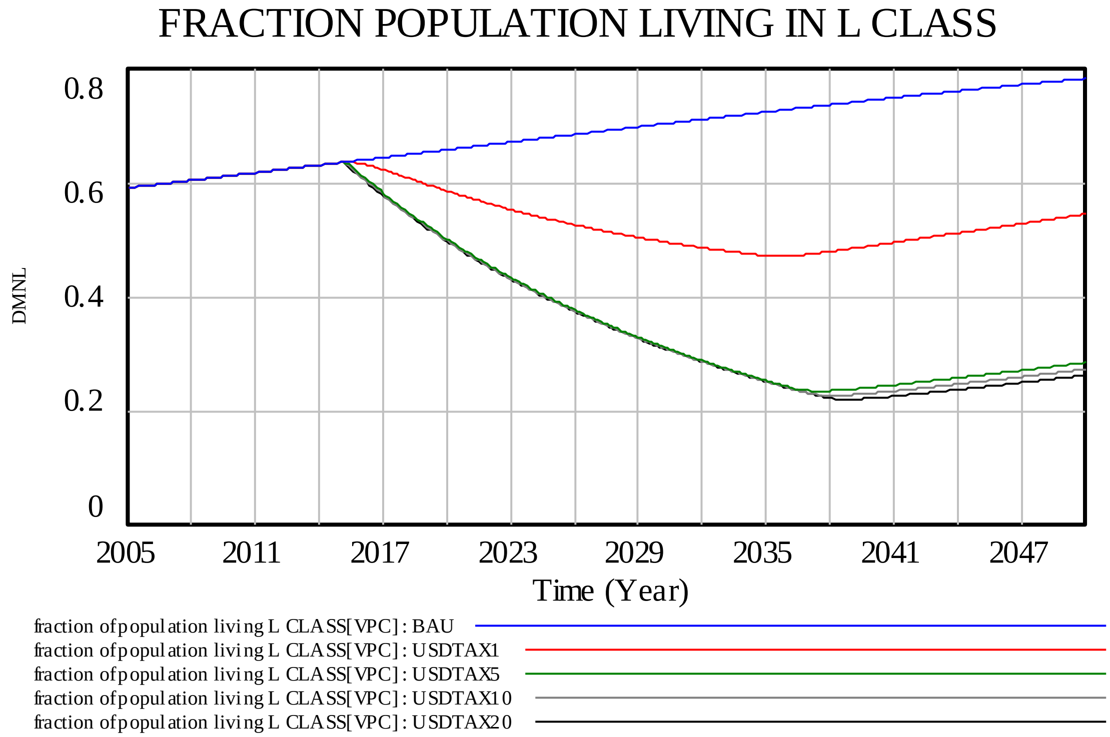
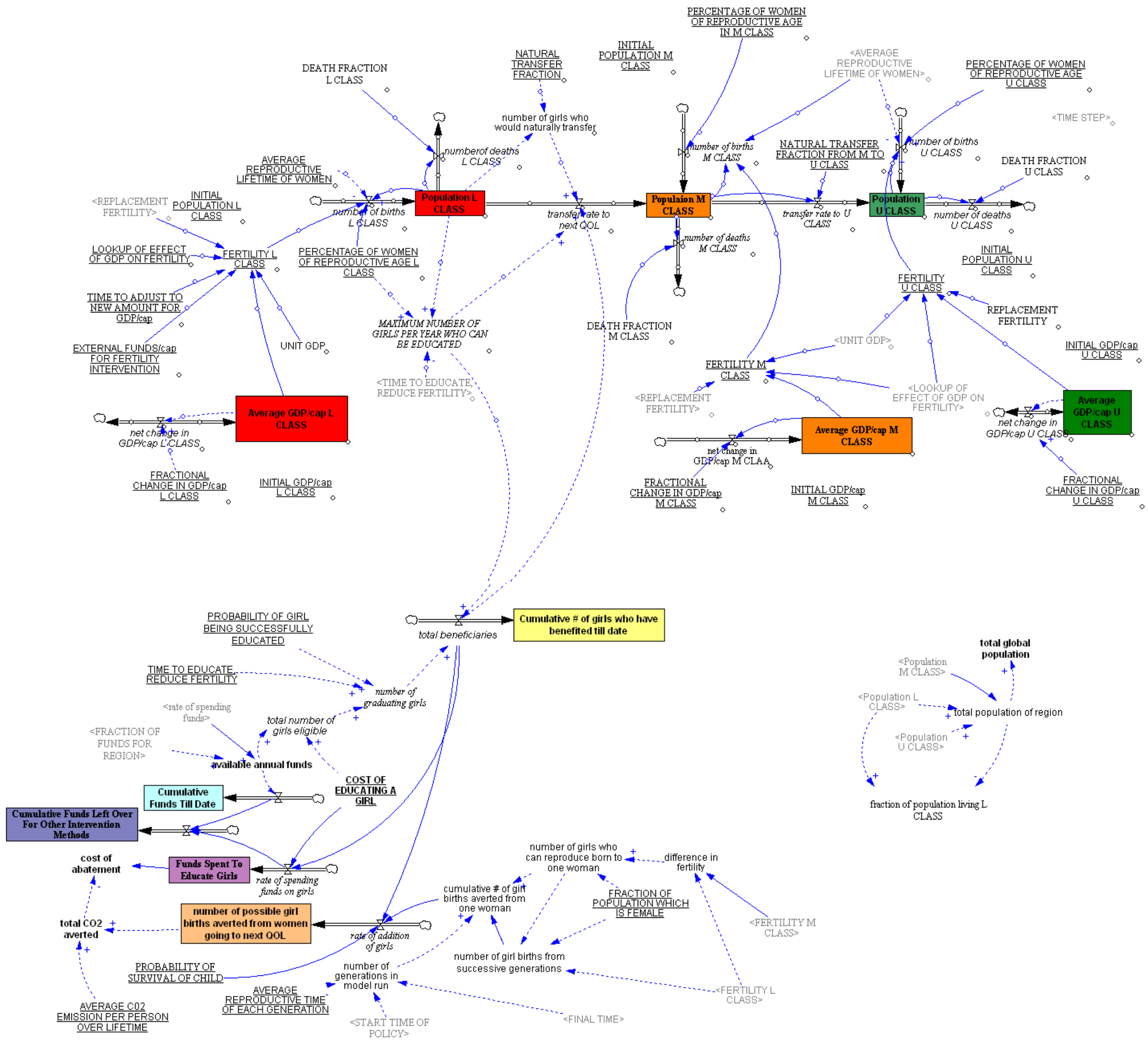


Figure 15 Fraction of population living in L Class relative to total population of the VPC region.

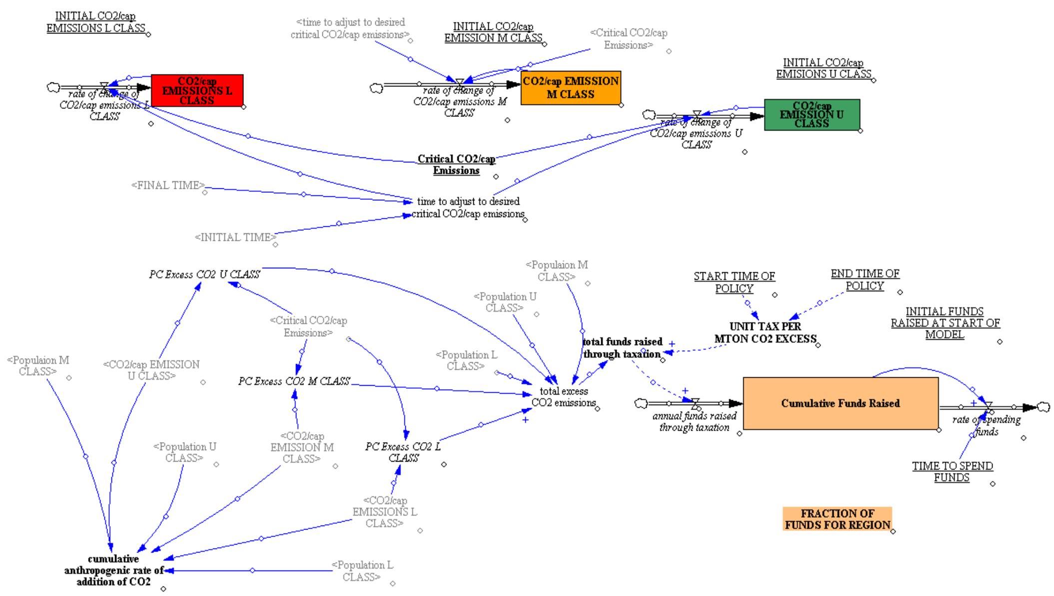
Other variants of the model show what would happen if

- external funding, not raised through excess per capita CO2 emissions, were to be contributed directly to fertility control measures for the population living below acceptable quality of life in the poorer regions.
- Portions of the funding were to be redistributed back to the developed countries as incentives to reduce consumption?
- Resource constraints were applied and what would be the scenarios under which collapse could be averted?

POPULATION STRUCTURE OF EARTHSAFE MODEL (Similar for each Region)



CO2, TAXATION STRUCTURE OF EARTHSAFE MODEL
(Similar for each class in each region)



MODEL AND MODEL EQUATIONS AVAILABLE FOR DOWNLOAD FROM THE FOLLOWING WEBSITE: www.earthsafeonline.com/esmodel.zip

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