Building the Framework for Absolute Sustainability

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Abstract: There is a truism in Engineering that requires that a problem cannot be solved until it has been adequately defined. Sustainability can be perceived as a Wicked Problem, which suggests that it has not been adequately defined. Perhaps Sustainability resists definition, but a more optimistic approach would be to try a different way to define it. In this paper, we advance a means of solving the Sustainability problem from first principals, in a manner that is intended to be universal, objective, sensitive, and repeatable. It is expected to be applicable for any scale of setting, in any culture, regardless of the resources, skills, and technology that is available. It is intended to rely on units of Sustainability, rather than indicators, with thresholds derived from the units themselves.

We would measure how long it takes people to meet their needs, how effectively people use their time to meet their needs (e.g. what time-weighted fraction of needs are met), and the consumption of resources and production of wastes, throughout the population of a community. From these measurements, we can determine the relationships between resource consumption and quality of life. From the relationships, decisions can be made to maximize quality of life of the community while minimizing negative ecological impacts, and achieve Global Sustainability at a community scale.

Keywords: Human Development, Technological Development, Absolute Sustainability, Time/Resource Curve, Needs

Introduction

For many years, Sustainability has been a focus of intense scientific study. For nearly 50 years, Sustainability Science has been exploring the ideas surrounding how people can live on the Earth in perpetuity. Thirty years ago, the concept of Sustainable Development was popularized in Our Common Future [1]. Today, a myriad of journals, conferences, academic disciplines, institutions, and researchers are all focused on finding answers to the same basic question, but Sustainability has remained a Wicked Problem that has defied a general solution.

This paper uses units of measurement, rather than indicators, to quantify long-term quality of human life, while considering resource consumption beyond the capacity of the land being managed in perpetuity by any community, to define Absolute Sustainability at a community scale. From these definitions, a method is developed which can provide an Absolute Sustainability Assessment, allowing projects of different settings, scales, and disciplines to be assessed using the same units.

Problem statement

Sustainability is perceived as a Wicked Problem [2]. A Wicked Problem is one that is difficult or impossible to solve because of incomplete, contradictory, and changing requirements that are often difficult to recognize. There is a truism that no problem can be solved unless it is sufficiently defined. That suggests that a Wicked Problem is one that has not been, and perhaps cannot be, sufficiently defined.

Sustainability is the broadest topic that is possible in the current body of science. It spans engineering, biology, economics, psychology, politics, and so on, touching effectively all aspects of science in some way. Due to the complexity of interactions between causes and effects, no one discipline of science is capable of framing the correct

questions in a manner that can lead to complete answers. Expert specialists can describe the necessary conditions from their perspective, but are unable to provide for all perspectives.

Sustainability Science is well developed [3]. Since the 1970's, researchers have looked to how human activities have, are, and will continue to impact the environment's capacity to support human existence on the Earth [4]. There are well-developed goals, targets, and indicators of success and failure that are being actively used to guide policy and focus resources (such as the UN MDG framework [5]). Ultimately, the purpose of sustainability science is to examine "interactions between global, social, and human systems, the complex mechanisms that lead to degradation of these systems, and concomitant risks to human well-being."[6]

Sustainability Science tends to rely on indicators of sustainability. Each discipline can include the key proxy measures that represent the system from the specialized perspective, and by having a plethora of indicators, describe the system in its entirety as a mosaic. Challenges are created by such an approach and from a designer's perspective these include:

- The weighting of indicators will typically be subjective.
- The relationship between indicators will not be explicit.
- Indicators tend not to be predictive, so the response to a change can't be confidently determined.
- Designing for indicators will produce poor results when compared to designing with indicators.
- Indicators used are dependent on scale, setting, culture, and timescale.
- Indicators suitable for one aspect (social, environmental, technological) of the community won't be used with another aspect.
- The use of indicators may determine how different alternatives will compare to each other (more or less sustainable), but will not be able to determine if the alternative causes the community to be sustainable as an absolute.

It is our position that, to solve the Wicked Problem of Sustainability in a general sense, the first principles of Absolute Sustainability must be developed, either from definitions already in use in Sustainability Science, or from definitions developed to fill the gaps. From the definitions, units of measure of Sustainability will be developed, and the equations that relate the units together will be derived. Once all this is in place, the Wicked Problem should be tamed.

We are seeking to maximize social benefit, while minimizing negative ecological impacts, and by so doing, create a virtuous cycle that can be shown to create the conditions that allow for Global Sustainability at a Community scale.

Background

The philosophical foundation for the development of a method for measuring Absolute Sustainability has to be able to be used to winnow the work already done in Sustainability Science to find a self-consistent set of definitions that can span the range of perspectives found in Sustainability Science. In order to be able to say, with confidence and without caveats, that "This is (or is not) the most Sustainable alternative design and it will (or won't) allow the community to be Sustainable", the approach for Absolute Sustainability must be:

- **objective,** using measurable values that include units, instead of proxy measurements, subjective indicators or indices. The values measured must be able to be predictive.
- **repeatable**, so that anyone using the same data will produce the same results.
- **sensitive** to, but independent of, culture, climate, labour and resource availability, technology, scale of community, or an undefined future.
- **universal**, able to be applied to any or all social, technological, and environmental problems.

In addition to this foundation, several conjectures have been made to further constrain the possible definitions. These conjectures can be tested to determine their validity after the exercise is completed.

Conjecture 1: A community either is, or is not, Sustainable. There is a definable and measureable difference. Absolute Sustainability exists.

Conjecture 2: People either use their time to meet their wants and needs directly [7], or they use their time to convert resources into the means to meet their wants and needs indirectly.

Conjecture 3: There is a relationship within a community between resource use and time use in activities required to meet needs that is unique to every community. That relationship is sensitive to, but independent of: scale of community, technology availability, resource availability, climate, culture, economy, and an undefined future.

Reviewing the available literature, the following definitions have been included that are compatible with the conjectures and are consistent with the philosophical foundation.

Sustainability encompasses the simple principle of taking from the earth only what it can provide indefinitely, thus leaving future generations no less than we have access to ourselves [8]. To pursue sustainability is to create and maintain the conditions under which humans and nature can exist in productive harmony to support present and future generations [9]. Sustainability is about intergenerational and inter-regional equity [10].

Needs are aspects of human nature, and are universal and invariant [11]. While the needs themselves are uniform across cultures and populations, the means and methods used to meet needs are potentially unique to each individual.

Development is a process of increasing well-being within a community between two points in time [12]. Quality of Life depends on the possibilities people have to adequately satisfy their fundamental human needs [11].

Human Development enhances the freedoms, choices, and capabilities of a population [13].

Well-being is both a philosophical and economic concept related to how well a person's life goes for the person who lives it [14]. In philosophy, it is related to ethics and morality. In economics, it is related to wealth and quality of life of a group [15]. As a concept, it has no clear definition, or even a general consensus view, although there have been many efforts to define and quantify the concept [16]. Well-being is perceived as being highly subjective, so that it resists quantification. This will be explored further in this paper.

In addition to these definitions, several other sources are key to the building of this framework:

- **Sustainable Development is development that meets the needs of today without compromising the ability for people to meet their needs in the future** [1].
- **Daly's Rules** [17]:
  1. We must use renewable resources slower than they renew.
  2. We must use non-renewable resources slower than they can be replaced with renewable alternatives.
  3. We must produce wastes slower than the environment can absorb them or render them harmless.

Additional Definitions

The above definitions, while useful, do not lead immediately to the units of measurement of Sustainability. To do that, the definitions must be completed to include units.

Due to the confusion related to the appropriate definitions of Well-being, I will instead use the concept of '**Quality of Life**' within this paper. Quality of Life depends on the possibilities people have to adequately satisfy their fundamental human needs [11]. Quality of Life can be deconstructed into Potential Quality of Life and Actualized Quality of Life.

> **Potential Quality of Life** *is the time available within a community for activities other than those required to meet needs.* Technology can directly influence Potential Quality of Life by changing how efficiently people use their time to convert resources into the means to meet their needs.

> **Actualized Quality of Life** *is the time within a community that would be available for activities other than those required to meet all needs, as if all needs were met.* There will be obstructions within a community that prevent needs from being met that are not addressed by efficiency, so they would have to be addressed through increasing the effectiveness of individual, families, or the community as a whole at meeting their needs.

Technological Development *is the creation or enhancement of systems of infrastructure with an expectation of an increase in people's efficient use of their time to convert resources into the means to meet their wants and needs.*

Infrastructure *is an investment of time and resources with an expectation of a return on that investment in the form of time and/or resources into the future.*

Sustainable Technological Development *is Technological Development that specifically considers the availability of resources in perpetuity and the time required to meet needs.*

It can be assumed that people act at all times to meet their perceived needs, if at all possible. Therefore it can be predicted that if people have unmet needs and there is sufficient time and resources available to meet their needs, there must be obstructions within the self, the family, or the community that prevents the individual from meeting those needs. These obstructions can be quantified by measuring 'Effectiveness', which is the ratio of the time spent at any group of activities that actually meets needs within the population, divided by the time spent at that same group of activities, regardless of how needs are met.

Human Development *would enhance the freedoms, choices, and capabilities of a population by identifying and removing obstructions that prevent people from meeting their needs effectively.*

Sustainable Human Development *is Human Development that considers specifically the benefits for the community in perpetuity.*

Analysis

Units and axes
If people use their time to convert resources into the means to meet their needs, there would be a relationship between time required to meet needs within a community and the resources used within that community. This predicts two separate axes associated with Technological Development.

Also, if people use their time to meet their needs directly, then the assumption must be that people that use less than 24 hours per day to meet their needs will have all their needs met, unless there is something that prevents them from doing so. This would manifest itself as a measure of effectiveness. Effectiveness is unitless, as the ratio of the time that is used to meet needs by the people who have their needs met, divided by the time used by all of the people, summed either for each need or for each group of needs. This can be plotted against either time use to meet needs or resources used by the community. A third axis is not required to represent a ratio without units.

With these two axes together, social benefits and negative ecological impacts can be assessed and, through a process of optimization, ensure that communities can be as sustainable as possible.

Negative Ecological impacts
Community managed biocapacity (CMBC) is the biocapacity of the land being managed by the community that serves the community. It does not include land that is being used for exports or managed by others and imported. Generally, it would be the lesser of the Ecological Footprint [18] and the Biocapacity of each Biome managed by a community, summed for all biomes. When community consumption is more than the CMBC, it means that resources are coming from 'Away' or 'the Future'.

If resources come from 'Away', then at any time, the resources could become unavailable at any price, due to any number of possible market disruptions. These could include resource exhaustion due to mismanagement by others, trade stoppages due to infectious diseases, war and famine preventing extraction of resources, growing demand from where the resource is sourced, etc. In any case, the resource could cease to be available and no specific action within the community would prevent that.

If resources come from 'the Future', ecological interest does not keep up with extraction, so that ecological capital becomes degraded. Depending on the ecological interest rate (e.g. the maximum sustained yield/total mass of resource), the tolerance of excess extraction may be very limited. Fish, for example, have an ecological interest rate in the order of 10%, which means the ecological capital may only be in the order of 10 years of production. Soils have an ecological interest rate in the order of 0.1%, so that there can be much more degradation before collapse. Regardless of the interest rate, however, if the Ecological Footprint exceeds the Biocapacity, degradation of the resource will occur in the foreseeable future.

Negative ecological impacts could also be measured using the Planetary Boundaries concept [19], by identifying the capacity of the ecological services within the Community to produce resources and absorb wastes. One distinction of this approach is that the various processes can occur simultaneously on the same parcel of land, while the Ecological Footprint approach assigns only one biome to any given area of land. Using Planetary Boundaries would require a different calculus, but would be equally valid.

Social Benefit
The social benefit side of the math requires observing three different aspects of the community: the time required by individuals to meet needs of the self, family, and community; how effectively people are able to use their time to meet their needs; and the Future Time Cost of over-consumption.

Time required to meet needs
People perform activities to meet needs or to convert resources into the means to meet their needs. Activities that the community believes would be expected to meet specific classes of needs (e.g. rest, food, shelter, clothing, community development, child care, security, etc.) can be grouped. Activities that are required to allow other activities that specifically meet needs can be considered needs, but it is up to each community to define the boundary of needs that they intend to use. Thus if 'eating food' is a need, then 'gathering food', 'preparing food', 'consuming food', 'disposing of wastes' could all be considered as activities that meet the need. For example, in Canada, we believe that we have food security. Therefore, we may consider all activities related to growing, handling, transporting, processing, selling, and shopping for food to be needs, but we may decide that importing food does not meet a need.

Effectiveness
Effectiveness is the ratio of the time that is used to meet needs by the people who have their needs met, divided by the time used by all of the people, summed either for each need or for each group of needs. It requires that there is a symptom related to unmet needs.

For example, if fitness is a need, then obesity could be a symptom of that need not being met. To calculate the Effectiveness of the community using fitness related activities to meet needs, one would need to cross reference obesity against the time use studies that indicate the time spent at fitness related activities.

Future Time Cost
There will be an impact on the time/resource curve for a community with the loss of an over-exploited resource. This impact is, at a minimum, the slope of the time/resource curve at capacity, times the magnitude of the overconsumption. This assumes that there are no synergistic effects.

This represents how much additional time the community would require to meet their needs if there was an incremental loss in resource availability to the community as a whole. If each segment of the population is considered separately, it is possible that the collapse of the resource would affect the poorest segments of the population more, due to the reduced ability to finance acquiring a less useful or more expensive alternative.

Method derived from units

Technological Development is the creation or enhancement of systems of infrastructure with an expectation of an increase in how efficiently people use their time to convert resources into the means to meet their wants and needs. Sustainable Infrastructure is an investment of time and resources with an expectation of a return on that investment in the form of time and/or resources into the future, when considering only the needs of the community and the resources available in perpetuity.

Any Sustainable Infrastructure is expected to improve the PQoL of the community [19]. This can be demonstrated by starting with the time required to meet needs within the community without the infrastructure and subtracting the time required to meet needs within the community with the infrastructure in place. From this, the Future Time Cost (from consuming more renewable resources than the biocapacity of the community can maintain in perpetuity) and the Time Penalty (from consuming non-renewable resources that will become exhausted during the life cycle of the project) must be subtracted to find the change in the Potential Quality of Life, and by using the Effectiveness of the community, determine the Actualized Quality of Life of the community.

This math is described more fully in Appendix A.

Data used in the following fictive example are within Appendix B. It relies on data from the Time Use studies of GSS 19 [20], and the distribution of resource use from Size Matters [21]. Figure 1 shows the community data, compiled using quintiles of household income. TU is the Time Used to Meet Needs, and Eff is the Effectiveness of the members of the community at meeting their needs. Subsistence is calculated at the point on the curve where people would need 24h/d/ca to meet needs. CMBC is the Community Managed Biocapacity.
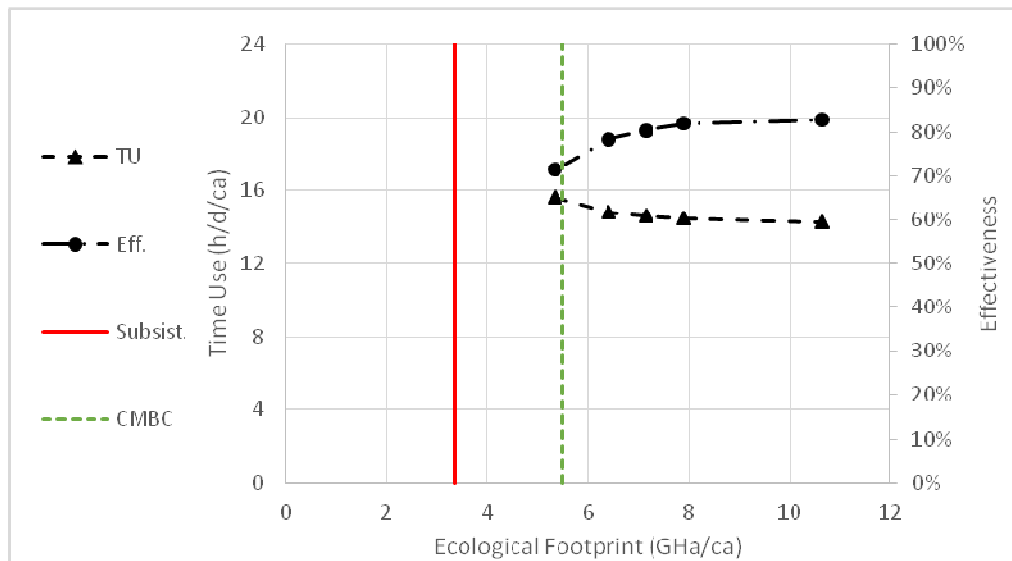
Figure 1: Community properties for a fictive community

The relationship between Effectiveness and Ecological Footprint is extrapolated from Canadian Data. It suggests that average Effectiveness decreases with resource scarcity. The relationship between Time Use to Meet Needs and Ecological Footprint comes from Canadian Data from 2005. It has an R^2 of better than 98%, using deciles of household income (shown in Figure 1 as quintiles of household income).

Figure 2 shows the results of previous work by the author on Potential Quality of Life [22]. The Future Time Cost, calculated from the slope of the Time/Resource curve at capacity, multiplied by the magnitude of consumption over capacity, causes the community to reach a maximum of PQoL at capacity. This produces 4 distinct economic ranges:

1) Consumption is Below Subsistence- There is insufficient resource consumption to support the population and significant depopulation would be expected.

2) Consumption is Below Capacity- Any increase in consumption results in an observable reduction in the time required to meet needs. Conventional Economics was developed using this as the basis of the analysis. Even considering negative ecological impacts, growth is good.

3) Consumption is Beyond Capacity- Any increase in consumption will produce an ever-declining reduction in the time required to meet needs. If considering negative ecological impacts, growth is bad. Conventional Economics doesn't provide satisfying answers.

4) Consumption is Beyond Hope- When the resources being over-consumed are fully exhausted, there will be insufficient resources to support the population at any level of consumption. Economic and ecologic collapse is inevitable: it's just a matter of time
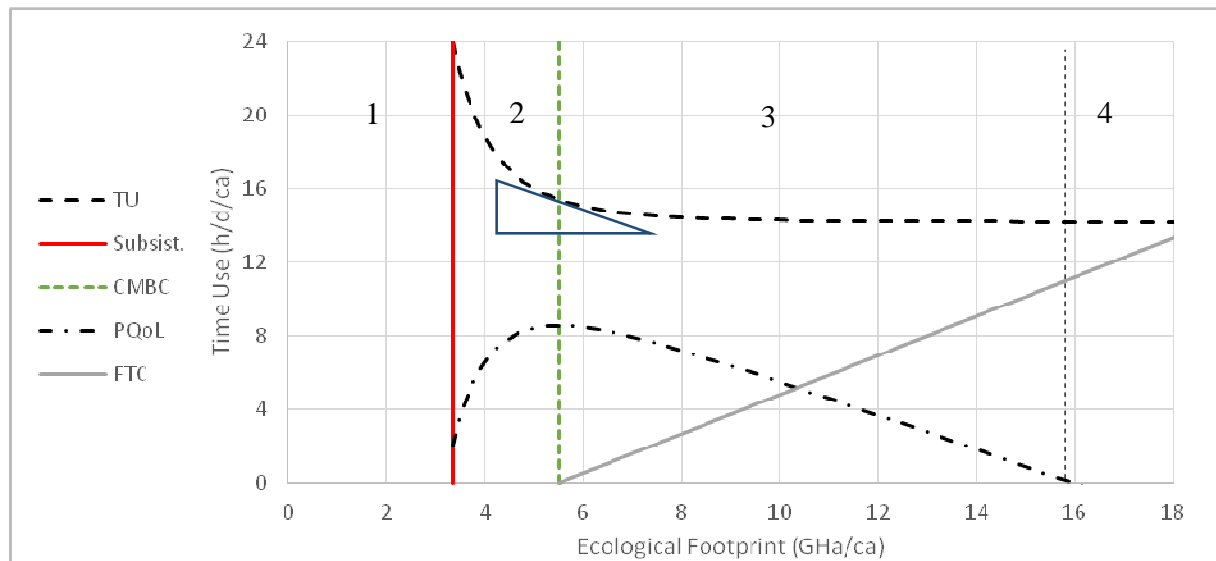
Figure 2: Development of Potential Quality of Life

Technological Development will tend to modify the PQoL of a community. As can be seen in Table B5 in the appendixes, the Time Use to meet needs of the richest quintile of the community is (947 – 880=) 67m/d/ca less than the Time Use to meet needs of the poorest quintile of the community. When considering the Future Time Cost associated with over-consumption, the PQoL of the richest is (502.2 – 270.5=) 231 min/d/ca less than the PQoL of the poorest. Or, said another way, if every rich person gave up the goods and services that a poor person couldn't afford, it would cost the individual about an hour per day in extra time required to meet their needs, but it would save the community nearly 4 hours per day in the long term, once the effect of resource exhaustion was considered. The immediate time cost would be impossible to work past politically, unless it can be made up through some other means.

Human Development seeks to increase quality of life by increasing the effectiveness of people's use of their time to meet their needs (and wants). The focus is on Actualized Quality of Life (AQoL) which is the time available for other activities after needs are met, as if all needs were being met, by identifying and removing the obstructions within the self, family, and community that prevent needs from being met.

Sustainable Human Development would be the process of enhancing the quality of life within a community between two points in time by removing the obstructions within a community that prevents the needs of individuals, families, and/or the community as a whole from being met, in such a manner as those enhancements would be available in perpetuity. Most Human Development will have a good chance of being sustainable automatically because of the relatively small required investment of resources. One must ensure that the use of resources to increase the Potential Quality of Life does not impede the Actualized Quality of Life. Also, one must ensure that changes to critical resource availability does not impede AQoL in the future as well as show that ongoing improvements are available, to allow for future changes in demographics, priorities, etc.

Effectiveness is the measure of the efficacy of the community in the delivery of needs to the community as handled by the social systems that supply those supports in the fulfillment of needs. This measurement requires combining time use studies and research into the symptoms of unmet needs.

While the calculus of sustainable infrastructure is of obvious importance for the creation of sustainable communities, the development of the people within those communities will determine how effective the efforts at sustainable development are. The identification of needs, from the standpoint of sustainable human development, is invariant and the needs are universal, yet the attempts, successful or not, at fulfilling those needs manifest in a multiplicity of ways. Humans are complex beings and we function as individuals and collectively in such a diversity of ways, that it would seem a difficult task to identify and assess this variety. However, all this diversity has at its foundation the same desire, to satisfy needs. It differentiates when we consider the ways in which we attempt to do

that and the fact that each individual has a unique set of needs, which while universal in theme are unique in response.

Identification of Obstructions

Obstructions are those things that limit our effectiveness at achieving our goals of well-being. Some obstructions are so bad as to limit our chances for survival, on the personal level. And then on the societal level, we have created a vast array of obstructions to our avowed goals of well-being, even as we claim that these things will bring us closer to our goals. Therefore, in the process of sustainable human development, we need to focus on the identification and elimination of obstructions to our goals. Many obstructions are circumstantial, others are self-inflicted, but they might be circumvented through the process of sustainable human development.

Personal obstructions to the attainment of basic and desired needs include mental illness, substance abuse, and poverty. Often these issues are beyond the control of the individual, such as many mental illnesses, while others are the result of poor choices, like substance abuse. Of course, these personal issues can be compounded as comorbidities, where the instance of mental illness, for example, bipolar disorder, is exacerbated by an addiction to methamphetamine. And they can also be influenced by wider problems, in the form of familial and community obstructions.

In families, various problems can exist and these can take the form of domestic and child abuse, poor health and hygiene, or low income or unemployment. At the community level, there may be endemic poverty, environmental and social injustice, or a lack of employment opportunities. Larger societal issues, like racism or gender inequality, certainly influence all communities, families, and individuals within the society. This is the reason why, beyond the calculations of sustainability for groups or communities, a concerted effort and the political will to change policies and legislation to afford people the opportunities to make sustainable choices and truly be the social safety net that we are fortunate enough to have within many of our developed nations.

Removing Obstructions

As we have already seen through the definition of basic needs, exemplified through the creation of UN mandates for Sustainable Development Goals or the Social Determinants of Health, as examples, while sustainable technological development can provide the means to live sustainably and there are international agreements and action plans, it is up to individuals, in their homes and in their communities, to actualize those potentials.

This process would involve identification of the impediments in society and addressing them at the individual, family, and community levels. We certainly already do that in many ways throughout communities, with a diversity of programs for all manner of issues, from self-help programs, to therapy groups, to individual professionals trained to assist those suffering from the impediments to return to full functioning. We require a more integrated and focused effort collectively to promote the elimination of these obstructions, before they become chronic issues for people, families, and communities. This requires the efforts on the parts of these individuals and communities, but it also requires the political will and action to actually promote and encourage the enactment of these goals. In these ways, individuals and their families, communities, and even, culture and society in general, can move toward a more sustainable and fully flourishing existence with attendant increases in quality of life.

To use poverty as an example, a focus of all UN human development programs, there are local groups and associations that attempt to help members of their communities who live in poverty. At municipal, provincial, and federal levels, quite often, there are committees that consider poverty reduction strategies to develop local, provincial, and federal policies for poverty reduction. Various groups conduct studies of the effectiveness of these programs, from the local level groups themselves as self-auditing measures, to municipal and regional bodies that oversee such programs, to sub-committees and task forces at provincial and federal levels, to attempt to establish poverty reduction policies and enact legislations to lessen the impact of the conditions of poverty and assist people to escape it. Through the analysis of these programs and individual responses, we can use a measure of effectiveness to demonstrate that removing obstructions that prevent people from meeting their needs is effective.

All examples, from community to international efforts at sustainable human development, identify the explicit social and environmental justice implications of a truly sustainable human future. We realize our responsibilities to all people; we just need to actively and consciously work towards these goals, now and into the future. However, "achieving an equitable and enduring sharing of the fruits of development, within and across generations, is not straightforward. On the one hand, the collective resources available for making the necessary advances have never been greater… On the other hand, human activity, if it continues along a business-as-usual path, imperils the continuity of the gains so far, as well as the potential for advances in the future, both for ourselves and our descendants." [23]

Social Justice

Any sustainable development (human or technological) must not reduce the AQoL for any identifiable segment of the population. This may mean that investments in infrastructure must be coupled with investments in social programs or that reductions in consumption for today that will produce a subtle increase in the time required to meet needs today with meaningful improvements of quality of life over a generation, will have to be joined with improvements in effectiveness that occur today.

Self-determined and actualized quality of life is the best possible quality of life. If we would listen to the disenfranchised, the poor, or the marginalized of our human populations, most often, that is all they ask. Certainly, the aid and the expertise to actually create the conditions for sustainable development will be accepted, but the fundamental need to create their own futures is the commonality within the groups and communities appealing for environmental and social justice.

Putting it Together

Figure 3 shows the community data extrapolated and includes the calculated Potential Quality of Life and Actualized Quality of Life. The data used in the following fictive example are within Appendix B, and are based on Canadian and US data. TU is the Time Used to Meet Needs, and Eff is the Effectiveness of the members of the community at meeting their needs. Subsistence is calculated at the point on the curve where people would need 24h/d/ca to meet needs. CMBC is the Community Managed Biocapacity.
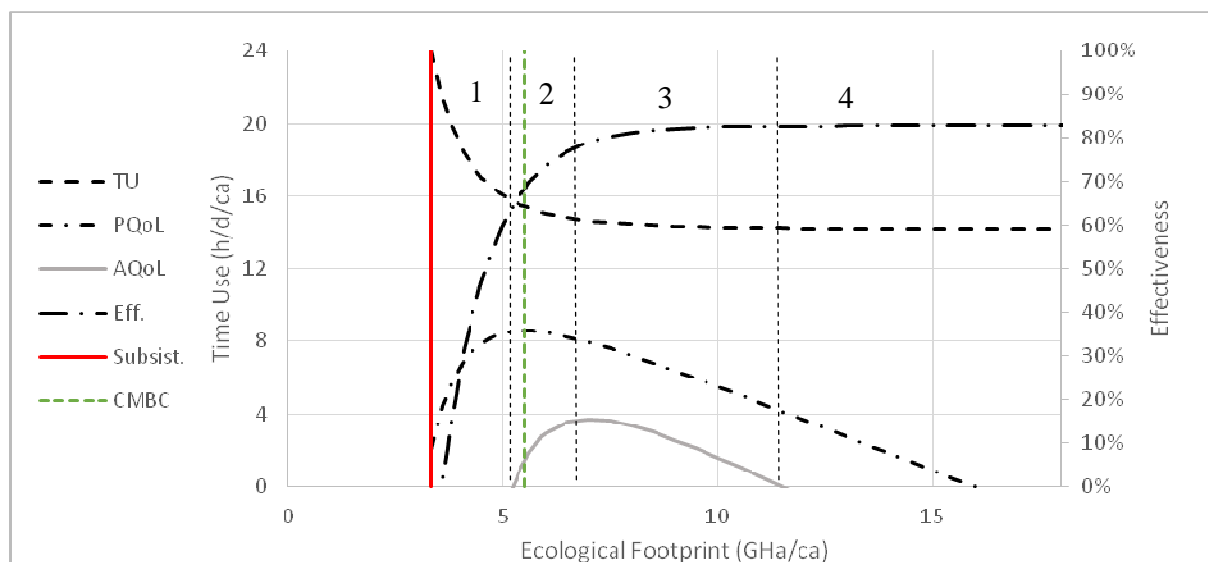
Figure 3: Development of Actualized Quality of Life

There are four new economic ranges:

1. Poverty- People spend less than 24 hours a day to meet their needs, but not all needs can be met. The Actualized Quality of Life is less than 0, which means it would take more than 24 hours per day for people to meet their needs, if all their needs were met.

2. Sustainable Growth- Increases in consumption will lead to long-term improvements in the Actualized Quality of Life. Resource consumption beyond capacity improves long-term quality of life more than the impact that occurs as a result of the loss of those resources.

3. Sustainable DeGrowth- Decreases in resource consumption will lead to a higher Potential and Actualized Quality of Life. When over-consumed resources cease to be available, sustainable lifestyles are still possible through Human Development.

4. Beyond Sustainability- When over-consumed resources become exhausted, sustainable lifestyles will not be possible, regardless of the Human Development undertaken.

Discussion

While the concept of needs is universal and invariant, the boundary of those needs has to be able to be refined by the community itself. This means that results produced for the Potential Quality of Life and Effectiveness in one community will vary somewhat with another and not be completely transferable. However, it would be expected that the AQoL would be fairly consistently comparable. If the community chooses to use a very austere boundary of needs, it would be expected that the population would have a relatively low Effectiveness. Therefore, while the population may not spent a great deal of time at activities that meet needs, it may have a proportionately lower fraction of needs that are met. Ultimately, this will need to be tested with real-world data.

The concept of Community Managed Biocapacity requires more than a buyer/vendor relationship. The vendor could at any time choose to sell to a different customer. Instead, the community must manage the land in a manner that allows the resources it generates to be available to the community in perpetuity. The Tragedy of the Commons [24] occurs when there isn't an enforced policy for management for resource availability in perpetuity.

People are aware of their time use and also their stress levels. If there is going to be a decrease in the time they have available after all of their needs are met, they will resist it. This is why economic growth has been a mantra for growing the middle class and maintaining a stable democracy. However, as we can see, the time/resource curve goes flat after some minimum level of consumption. It is effectively impossible to have more time by consuming more in a First-World setting. Maximal long-term potential quality of life will occur at consumption levels near capacity. The only way to have a meaningful impact on the Actual Quality of Life would be to improve Effectiveness. In First-World settings, increasing Effectiveness will have a much greater impact on the Actual Quality of Life than any change in resource consumption. In less developed areas, the potential increase in Quality of Life is much greater, so the case for Technology is easier to make.

Doughnut Economics

There is a concept referred to as Doughnut Economics [25], which considers an ideal 'space' where consumption is neither too great for the ecosystem to support, or too restricted to support the population.

Figure 4 shows the classic representation of Doughnut Economics. Too little resources utilized and the social foundation of the community is disrupted. Too much resource extraction and the ecological systems fail. The 'safe operating space' described is comparable to the Actualized Quality of Life in Figure 2.

The differences between Doughnut Economics and this approach include:
-This approach can quantify the effect of degrees of overshoot and shortfall.
-This approach condenses all of the social indicators into a single measurement of Effectiveness.
-This approach is using Ecological Footprint, rather than Planetary Boundaries.
-This approach is specifically predictive.

The parallels include:
-Unpaid work is considered equally with paid work.
-The value of ecological services that support people is included.
-Economics is understood as the matter, energy, and labour flows in, out, and through the community.
-Needs are listed explicitly.
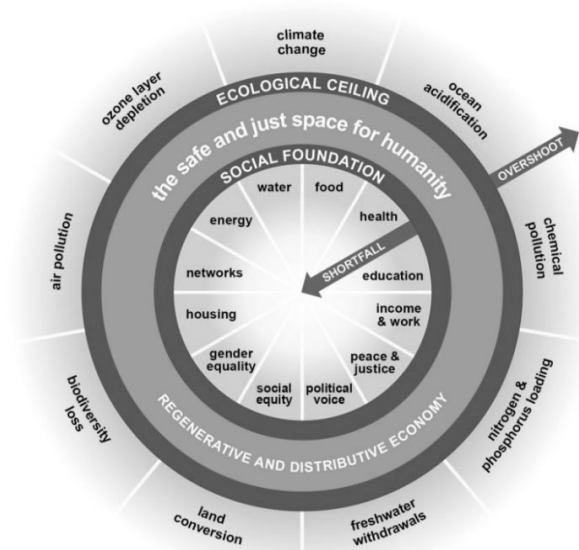
-Negative environmental impacts are explicitly considered.

Figure 4: Doughnut Economics

Many of the indicators in the Doughnut could correspond directly with the activities measured in this approach.   If both "fitness" and "health care" are needs, with "obesity" and "lack of access to suitable care" as indicators of unmet needs in this approach, the corresponding indicator in Doughnut Economics would be 'health'.

Limits
There are limits that come from the math used because of the aspects of the system that the numbers describe. These limits produce four necessary and sufficient boundaries for Absolute Sustainability at a Community Scale. To prevent a significant reduction in the quality of life in the future, Communities must:

- Not extract resources or produce wastes faster than the landmass managed by the community can support in perpetuity. This ensures negative ecological impacts are minimized.

- Not import resources or export wastes required to meet needs. This ensures the community can be self-sufficient if required, thereby providing resilience.

- Not require more than 24 hours per day per capita to meet all the needs of all the people in the community, while considering long-term impacts. This ensures the community can be stable in the absence of outside support.

- Retain a non-declining portion of the landmass being managed by the community in a 'wilderness' state, that is neither a source of resources nor a sink for wastes. This ensures the gaps in the knowledge of ecological systems does not immediately lead to the collapse of those ecological systems.

To ensure social justice, any development activity that is expected to provide an improvement in the Actualized Quality of Life for any subset of the community must not cause a decline in the Actualized Quality of Life of any other subset. While this is important to ensure the community will support the development initiatives, it is not specifically required by the mathematics to occur.

For a community with high populations and low resources, such as a city, it will be necessary to develop a co-management relationship with surrounding communities, so that the needs that can be met in the city, such as education and health care, and the needs that can be met in the rural areas, such as food production and resource extraction, can be coordinated. The scale of communities that have achieved Absolute Sustainability will tend to be

beyond the typical municipal borders. The more complex the society is, with broader range of technologies and resources in use, the larger that scale has to be.

At a smaller scale, such as individual, household, or business, Absolute Sustainability cannot be achieved in a meaningful way. However, that smaller scale can be said to be adding to the Sustainability of the community, if it is ensuring at least one of the four points above is closer to being met, without negatively impacting the others.

A Sustainable Business would have to show that any one of the four conditions of Absolute Sustainability that is currently not achieved by the community is improved and none of the rest are worsened, either for the community as a whole, or for any identifiable subset of the community. Table 1 shows the conditions, what would be required to demonstrate to prove an improvement and what the community threshold would be for this condition to be met.

Absolute sustainability condition	To cause improvement	Community Threshold
Ecological overshoot	(EF-CMBC) future < (EF-CMBC) current	CMBC is not less than EF
Not import for needs	Imports future < Imports current	No imports to meet needs
Can meet all needs in 24 hrs	AQoL is increased	AQoL > 0
Retain wilderness	No increase in demands on wilderness	No demands on wilderness

Table 1: Sustainable Business requirements

Testing Conjectures
Three conjectures were made early in this paper that remain to be tested.

Conjecture 1: Absolute Sustainability exists.

Conjecture 2: People either use their time to meet their wants and needs directly or they use their time to convert resources into the means to meet their wants and needs indirectly.

Conjecture 3: There is a relationship within a community between resource use and time use in activities required to meet needs that is unique to every community.

In the absence of a community that is Sustainable, Conjecture 1 cannot be tested. If it is not true, then all the efforts being undertaken will only slow the collapse of industrialized cultures.

Conjecture 2 appears to be true and seems to span the whole of the human experience. It is an expansion on the first sentence in the preface of the Wealth of Nations [7] to consider the possibility of limited resources, and is the foundation of our economic theory.

Conjecture 3 is demonstrated by the Canadian data presented and there is no reason to expect that it is unique to Canada.

It is our position that these conjectures can be taken as fact.

Example

The Tum Somnum Mattress Company develops a better mattress. Market testing has shown that about 80% of the population of the community has their need for sleep met, but for the fraction that doesn't, about half will get a benefit from this new mattress. They expect 10% of those people who are looking for better sleep to purchase a mattress within the next year. People that are currently not sleeping well, but would benefit from the mattress, will go from spending an average of 400 minutes a day at 'rest' activities to 500 minutes per day. The time required to design, manufacture, maintain, and eventually, dispose of the mattress is expected to average 48 hours per customer over the 10-year lifespan of the product. The mattress weighs 20 kg and uses 8 kg of materials that don't come from the resources that are managed in perpetuity by the community. The 12 kg of materials that are sourced locally have an ecological footprint of 0.1 GHa/ca, when averaged over the lifespan of the product.   The community has a Biocapacity of 6 GHa/ca and uses the Time/Resource curve shown in Figure 2. It currently has an Ecological Footprint of 10 Gha/ca.   The community spends 1000 min/d/ca to meet all of its needs today and has an Effectiveness of 80%. There is no expected change on the land set aside as wilderness.

Is this a Sustainable enterprise?

The community has already decided that 'sleep/rest' is a need and that 'insomnia' is a symptom that this need isn't met. The time-use data provided in Appendix A will be used for creating the Time/Resource curve. It is assumed that 2% of the population will purchase these mattresses over the next year.

	Symbol	units	Existing	Proposed
Average time spent at activity	Ti	Min/d/ca	480	481
Time spent for those with sleep need met	Tim	Min/d/ca	500	500
Time spent for those with sleep need unmet	Tiu	Min/d/ca	400	400
Fraction with sleep need met			80%	81%
Time spent at all needs	T	Min/d/ca	1000	1001
Effectiveness (sleep)	Effi		83.33%	84.20%
Effectiveness (total)	Eff		78.60%	78.97%
Time required to design, manufacture, maintain, decommission, each		Min.		2880
Product lifecycle	D	Yrs		10
Mass of product	M	Kg		20
Mass of NRR that won't be available at end of lifecycle	mi	Kg		8
Portion of lifecycle that NRR won't be available	D-Ri	Yrs		10
Time Penalty as fraction of Basic Time Benefit	P			0.4
Fraction of population purchasing the product				2%
Basic Time Benefit	BTB	Min/d/ca		-1
Change in Ecological Footprint	ΔEF	GHa/ca		0.002
Slope of Time/Resource curve at capacity	T'(BC)	Min/d/GHa		-0.601
Future time cost	FTC	Min/d/ca		-0.0012
Tc/D(1-P)		Min/d/ca		0.0263
Potential Quality of Life	PQoL	Min/d/ca	295.8	294.8
ΔPQoL		Min/d/ca		-1.03
Actualized Quality of Life	AQoL	Min/d/ca	-15.7	-10.16
ΔAQoL		Min/d/ca		5.57

Table 2: Example Analysis

In one year, these mattresses would add significantly to the Actualized Quality of Life of the community, although the community would remain outside of the zone where it can be Sustainable. There would have to be analysis on the current alternatives that would be replaced by this technology to determine if adding 0.1 GHa/mattress over the lifespan of the product is better than the status quo it would replace. Likewise, further assessment is required to determine if the imported resources (or exported wastes) for the community are changed as a result of this product.

Therefore, the best that can be said is that it has the potential of contributing to Community Sustainability.

Conclusions

Future research
- This paper uses fictive data sets to create the Effectiveness function. Studies of various communities using actual data would be able to demonstrate the real range of Effectiveness that would be expected in various situations.
- Different choices in the scale of community investigated will make a meaningful difference in the AQoL of a community. A city in isolation will have a lower AQoL than the surrounding region and the region may have a lower AQoL than the province/state. Yet there will be scales of community that would not have sufficient cohesion to be able to work together, creating an upper limit of community scale where 'bigger' is no longer 'better'. A study to examine how the AQoL can be maximized for a country as a whole by choosing different scales of communities within the country can investigate the effect.
- Effectiveness can be affected by Human Development. Research that co-related expected improvements in effectiveness with the level of effort required to achieve it would be able to be used to identify the 'low hanging fruit' for any given community.

- Communities choose the boundary of needs that they intend to use for their planning. While it is expected that the process of including Effectiveness should generally remove much of the subjectivity that could come from this approach, it would have to be investigated in detail to confirm. It may be that the results produced may only be consistent within individual communities, and not between communities.
- This approach requires an existing community, and would not be able to be used from a 'blank slate'. It should be possible to modify the general concept to derive a method that would work on a new community, such as a Martian colony.
- This approach is definitely human-centric. By setting aside wilderness, this is ameliorated to some extent. The amount of land that should be set aside has not been suggested in this work, and there would be multiple ways this could be determined.

Acknowledgement

Final Word

This is a framework for Global Sustainability at a community scale. It requires that an existing community decide the boundaries of needs that it intends to focus on, and requires data that is currently collected in many settings. It addresses over-consumption of renewable resources, consumption to exhaustion of non-renewable resources, and both efficiency and effectiveness of how people use time to meet their needs. It allows comparison of projects and processes of different disciplines and settings, so that the best investments for Sustainable Communities can be made.

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Appendix A

Math Used

People use their time to convert resources into the means to meet their wants and needs. If fewer resources are available, more time is required. If resources are being overconsumed, they will cease to be available, forcing there to be a greater time required for needs to be met. Without considering synergistic effects, the minimum time cost associated with consuming at a rate beyond the Community Managed Biocapacity would be the slope of the Time/Resource curve for the community at capacity, times the amount of overconsumption. It is implied that under-consumption will lead to the recovery of over-stressed ecosystems, so this slope would extend to produce a subtle benefit for under-consumption.

Since the Ecological Footprint method focuses on renewable resources, it doesn't fully address Daly's Rules concerning non-renewable resources. To correct for this, a time penalty can be applied that diminishes the benefits incurred from using nonrenewable resources that will become exhausted from the community during the lifecycle of the project. If locally sourced non-renewable resources become exhausted during the lifespan of the project, then the project will cease to be able to be maintained and the effective lifespan becomes truncated. A time penalty is applied to the project, as a whole, that is the product of the fraction of the project, as a whole, of the resource that will become exhausted and the fraction of the lifespan of the project for which the resource is exhausted.

Therefore, the entire equation for the Potential Quality of Life becomes:

$$PQoL = 24 - T + T'(CMBC) * (EF - BC) \qquad (1)$$

$$\Delta PQoL = T_0 - T_1 + T'(BC)(EF_0 - EF_1) - \frac{T_F}{D(1-P)} \qquad (2)$$

Where:
The subscripts of 0 and 1 represent the pre-development and post-development conditions.
PQoL is the Potential Quality of Life in the community, or the time available for activities other than those required to meet needs, while considering impacts of overconsumption.
T is the time required to meet needs.
T_c is the time required to plan, construct, operate, maintain, and ultimately, decommission the project.
D is the cradle-to-cradle lifespan of the project.
T'() is the slope of the time/resource curve.
BC is the Community Managed Biocapacity.
EF is the ecological footprint of the community.
P is the time penalty for using non-renewable resources that will exhaust from the community during the lifespan of the project.

$$P = (\sum m_i d_i / MD) \qquad (3)$$

m_i is the quantity of the resource used in the project that will exhaust during the lifespan of the project. The units of this quantity can vary from one resource to another. Landfill space, for example, is a NRR and the quantity used would be a volume, while steel may be mass.
M is the quantity of all the resources used in the project.

d_i is the duration that the resource will be exhausted. This is equal to $D-R_i$ and negative values would be treated as 0.

R_i is the resource longevity. This would be the time required to extract the current known reserves within the community, at the current rate of increase in consumption. Alternatively, if peak production of the resources has yet to occur and the time to peak is known, this can be taken as twice the time to peak within the community. If R_i is greater than D, d_i is 0.

$$AQoL = (24 - (24 - PQoL)/Eff) \qquad (4)$$

$$\Delta AQoL = (24 - PQoL_1)/Eff_1 - (24 - PQoL_0)/Eff_0 \qquad (5)$$

AQoL is the Actualized Quality of Life in the community or the time available for activities, other than those required to meet needs, as if all needs were met.

Eff is the Effectiveness of the community at meeting its needs. It is the ratio of the time spent at the activities expected to meet needs that actually do meet needs, to the time spent at those same activities, regardless if they meet needs or not.

$$Eff_i = \frac{T_{im}}{T_i}(1 - N_{iu}) \qquad (6)$$

$$Eff = T / \sum \frac{T_i}{Eff_i} \qquad (7)$$

Eff_i is the effectiveness of the community at meeting Need i.

Eff is the effectiveness of the community at meeting all of its needs.

T_{im} is the time used within the community at activities expected to meet Need i, by those people who have Need i met.

T_i is the time used within the community at activities expected to meet Need i.

N_{iu} is the fraction of the community with symptoms that they do not have Need i met.

T is the total time used to meet needs.

$$SV = \frac{\Delta AQoL}{NPV} \qquad (8)$$

SV is the Sustainable Value.

NPV is the net present value of the cost of creating, operating, maintaining, and decommissioning the project.

Any community that has a positive AQoL will be able to meet all of its needs using the resources it manages in perpetuity. Even as over-consumed resources become unavailable due to resource exhaustion, the community will still have the possibility of meeting all of the needs of all of its citizens in 24 hours per day per capita. Any alternative project, program, process, or product that produces a positive ΔAQoL can be considered Sustainable, even if the effort does not cause the community to have a positive AQoL. The alternative that has the highest SV will be the best investment from a Sustainability perspective.

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Please visit next page for Appendix B

Appendix B –Data

Table B1 – Time Use Data Summary

Household income categories from Time Use Data

	1	2	3	4	5	6	7	8	9	10	11	12
count	138	87	339	760	769	1517	1810	1551	1598	2126	1450	2307
Average time (min/d/ca)	985	1012	971	948	928	901	885	877	877	874	860	857
Stadev	255	228	250	233	229	237	241	243	243	241	248	246
Max	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440
80 %ile	1209	1245	1200	1156	1134	1110	1110	1098	1100	1110	1101	1095
Median	990	995	975	945	920	890	860	850	840	838.5	820	810
20 %ile	745	797	740	740	720	690	670	660	660	660	650	650
Min	240	546	135	210	325	20	100	40	90	60	210	110
Averages, per category (min/d/ca)												
Rest	566	578	577	563	550	537	521	524	513	508	504	500
Food	135	109	128	135	143	133	131	126	127	125	123	120
Clothing	28	20	22	27	25	24	26	24	23	27	23	21
Shelter	2	1	9	8	10	14	14	13	18	18	16	14
Fitness	22	35	29	25	24	24	28	28	28	32	31	30
Education	99	134	44	28	30	24	18	15	19	15	17	18
Childcare	11	21	16	19	17	16	19	24	25	27	28	30
H2O/hyg./sani.	72	75	74	82	78	69	73	69	66	64	63	62
health care	2	1	14	9	6	6	4	5	4	5	4	4
mobility for household	18	22	26	28	25	31	32	31	34	34	35	38
Community	27	11	25	20	16	20	16	15	17	16	14	14
mobility for community	4	5	5	4	6	4	4	4	4	4	4	4
Employment	54	59	72	78	113	157	197	221	228	241	272	278
employment to meet needs	17	24	27	32	47	74	91	104	111	117	128	127
mobility for employment	6	7	8	8	10	15	18	21	21	23	30	31

Source: Statistics Canada, Cycle 19 Global Social Survey, 12M0019XCB, 2006. This analysis is based on the Statistics Canada General Social Survey, Cycle 19: Time Use, 2005. All computations, use and interpretation of these data are entirely that of Douglas Nuttall, P.Eng.

Appendix B –Data
Table B2 – Ecological Footprint Data Summary

		1	2	3	4	5	6	7	8	9	10	average
						Deciles of household income						
	Food	2.06	2.15	2.14	2.14	2.14	2.16	2.15	2.16	2.13	2.24	2.13
	Housing	1.51	1.82	1.79	1.73	1.88	1.98	2.06	2.19	2.31	3.4	2.16
	Mobility	0.36	0.62	0.88	1.04	1.2	1.43	1.55	1.74	2.17	3.23	1.43
	Goods	0.56	0.74	0.82	0.85	0.93	1	1.09	1.16	1.33	2.11	0.97
	Services	0.55	0.68	0.71	0.74	0.79	0.82	0.83	0.89	0.95	1.48	0.74
	Energy Land	2.82	3.23	3.74	3.89	4.18	4.5	4.68	5.01	5.66	7.84	4.59
	Cropland	0.88	0.95	1.03	1.03	1.06	1.09	1.12	1.13	1.14	1.56	1.07
	Pasture	0.3	0.32	0.34	0.34	0.35	0.36	0.37	0.37	0.38	0.52	0.36
	Forest	0.89	1	1.05	1.06	1.17	1.23	1.31	1.41	1.48	2.21	1.29
	Built area	0.04	0.04	0.05	0.05	0.05	0.06	0.06	0.07	0.07	0.11	0.06
	Fishing Grounds	0.11	0.11	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.17	0.12
	Total	5.03	5.66	6.34	6.48	6.93	7.36	7.67	8.12	8.87	12.42	7.49

Ecological Footprint (Gha/household) using EF 1.0

from Size Matters, 2008, Canadian Centre for Policy Alternatives, By Hugh Mackenzie, Hans Messinger, Rick Smith

Appendix B –Data
 Table B3 – Combined Data

Deciles of household income

		1	2	3	4	5	6	7	8	9, 10
	EF	5.03	5.66	6.34	6.48	6.93	7.36	7.67	8.12	10.645
	count	1400	1402	1503	1613	1665	1601	1488	1377	2404
	rest	567	544	530	522	520	511	508	504	500
	food	132	138	132	129	126	126	125	123	120
	clothing	25	25	25	25	23	24	27	23	22
	shelter	8	12	14	14	15	18	18	16	14
	fitness	26	24	26	28	28	30	32	31	30
	education	46	27	21	17	16	17	15	17	18
	childcare	18	17	18	21	24	26	27	28	30
	H2O/hyg./sani.	79	73	71	72	68	65	64	63	62
	health care	9	6	5	4	5	4	5	4	4
	mobility for household	26	28	31	31	32	34	34	35	38
	Community	21	18	18	16	16	16	16	14	14
	mobility for community	4	5	4	4	4	4	4	4	4
	sum	960.0	914.3	893.3	882.2	876.9	875.7	874.0	860.7	857.0
	employment	34	135	175	204	224	233	241	271	277
	employment to meet needs	13	61	82	95	107	113	117	128	127
	mobility for employment	4	13	17	19	21	22	23	30	31

Time Use (min./day) of respondent, GSS Cycle 19

Appendix B - Data
Table B4 - Effectiveness

Need	Examples of symptom of unmet needs	Fraction of pop. with symptom Assumed values By Quintile of household income						Time spent by people with need met Assumed values Min/d/ca				
		1st Q	2nd Q	3rd Q	4th Q	5th Q		1st Q	2nd Q	3rd Q	4th Q	5th Q
Rest	insomnia	22%	19%	17%	15%	14%		530	520	510	500	490
Food	food insecurity	25%	12%	6%	2%	0%		138	132	128	122	118
Clothing	unsuitable for weather, culture	15%	5%	1%	0%	0%		22	21	20	19	18
Shelter	risk of homelessness	14%	14%	11%	5%	1%		10	12	14	13	12
Fitness	obesity	50%	50%	50%	50%	50%		40	40	40	40	40
Education	dropout	40%	20%	10%	5%	2%		40	20	15	15	15
Childcare	child neglect/abuse	32%	32%	32%	32%	32%		20	25	30	35	40
H2O/hyg/sani.	boil water advisory	10%	10%	10%	10%	10%		70	70	65	65	65
health care	lack of access to adequate care	25%	25%	30%	30%	35%		5	5	5	5	5
community	mistrust neighbours	40%	35%	30%	25%	20%		19	18	17	16	15
mobility	can't reach required places	25%	20%	15%	10%	5%		30	30	30	30	30
	total							924	893	874	860	848

Need	time spent by all people From Canadian statistics						Effectiveness Calculated					
	1st Q	2nd Q	3rd Q	4th Q	5th Q		1st Q	2nd Q	3rd Q	4th Q	5th Q	average
Rest	556	526	516	506	500		74%	80%	82%	84%	84%	81%
Food	135	131	126	124	120		77%	89%	95%	96%	98%	91%
Clothing	25	25	24	25	22		75%	80%	84%	76%	82%	79%
Shelter	10	14	17	17	14		86%	74%	76%	73%	85%	78%
Fitness	25	27	29	32	30		80%	74%	69%	63%	67%	70%
Education	37	19	17	16	18		66%	84%	82%	89%	82%	78%
Childcare	18	20	25	28	30		78%	87%	82%	87%	91%	85%
H2O/hyg/sani.	76	72	67	64	62		83%	88%	88%	92%	94%	89%
health care	8	5	5	5	4		50%	83%	78%	78%	81%	71%
community	27	31	33	35	38		42%	38%	36%	35%	32%	36%
mobility	32	35	37	39	42		71%	69%	69%	70%	68%	69%
total	947	903	893	888	880		74.7%	81.4%	83.3%	84.8%	85.8%	81.9%

Source: Statistics Canada, Cycle 19 Global Social Survey, 12M0019XCB, 2006

This analysis is based on the Statistics Canada General Social Survey, Cycle 19: Time Use, 2005. All computations, use and interpretation of these data are entirely that of Douglas Nuttall.

Appendix B - Data
Table B5 -Values used for fictive community

Community Managed Biocapacity	5.5	Gha/ca				
		By Quintile of household income				
		1st Q	2nd Q	3rd Q	4th Q	5th Q
Ecological Footprint (EF)	Gha/ca	5.345	6.41	7.145	7.895	10.645
Time Use to meet needs (T)	min/d/ca	947	903	893	888	880

Time Required to meet needs	$T = a\,EF^b + k$					
a=	83804	min/d/ca				
b=	-4.1157					
k=	851	min/d/ca				
$R^2=$	99.87%					
$T^{-1}(1440\text{min/d/ca})=$	3.34	Gha/ca	Calculated Subsistence			
Slope of the T/R curve at BC	-56.26	min/d/Gha				

		1st Q	2nd Q	3rd Q	4th Q	5th Q
Excess Resource Consumption	Gha/ca	-0.155	0.91	1.645	2.395	5.145
Future Time Cost	min/d/ca	-8.7	51.2	92.6	134.8	289.5
Potential Quality of Life	min/d/ca	502.2	485.8	454.4	417.2	270.5
Effectiveness		74.7%	81.4%	83.3%	84.8%	85.8%
Actualized Quality of Life	min/d/ca	184.5	268.0	257.1	234.5	77.2

Effectivenesss	$Eff = c\,EF^d + j$	
c=	-21.3	
d=	-0.968	
j=	82.82%	
$R^2=$	99.83%	