

QUANTIFYING SUFFICIENCY

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Abstract

There is concern about the adverse environmental impacts that arise from resource use associated with the provision of goods and services. Increased efficiency in resource use and adoption of sufficiency as a basis for consumption are possible responses. There has been a good deal of effort to enhance efficiency but little as yet to foster adoption of sufficiency. In part this reflects a difference with respect to quantification. There is a well-accepted approach for efficiency but not for sufficiency. This paper proposes an approach for sufficiency and illustrates it with a number of examples. It argues that adoption of this approach would enhance efforts to reduce resource use and provide an effective means to deal with rebound. Building on the foundation that the approach provides the paper recommends actions which provide a start toward deep societal change.

Introduction

Sufficiency in the consumption of goods and services emphasizes care and restraint. The idea that it should influence the way we live played a role in debates about the nature of a good life among ancient Greek philosophers ever since (McMahon, 2006). Part of this long-running discussion addresses the connection between human activity and the environment. This strand stretches back to Roman times and Seneca's view of a good life as one lived in harmony with nature (Bok, 2010). To pick it up, *How Much Is Enough?* (Durning, 1992) provides a useful point of departure. Today the work of Thomas Princen is central to the environmental strand. His treatment of sufficiency provides the context for the discussion in this paper.

For Princen the distancing of consumption decisions from their impacts on resource use and so on the environment is an important concern (Princen, et al., 2002). Making decisions about consumption that reflect due environmental concern is central to his notion of sufficiency. This is clear in his positioning of the concept:

Sufficiency is a class of principles sensitive to critical environmental risks, to the needs of management and self-management, when it is otherwise all too easy to evade responsibility for such risks. Sufficiency is an idea, a principle, indeed an ethic for sustainability (Princen, 2005, page 19).

For Princen the practice of sufficiency is integral to the pursuit of a good life. He describes the practice as “doing well by doing a bit less than the most possible” (Princen, 2010, p. 72). He has identified numerous examples of this sort involving actions taken by individuals, groups, businesses, and government agencies. Princen has linked the practice

of sufficiency to societal change. The preface to a recent volume he and his co-editor make the connection via a sequence of questions:

Now the questions before us are these: How should societies respond to reemerging and unavoidable biophysical constraints? How can they transition in ways that are peaceful, democratic, just, and environmentally resilient? How might they craft a society that lives well and well within the limits of this single planet? (De Young and Princen (eds.), 2012).

Princen has discussed the role of analysis and policy in bringing about change. In one of his papers (Princen, 2006, page 50) he sets out two possibilities:

Analytic and policy approaches to environmental problems can be roughly grouped into two categories. There are those that take current resource-use practices as given and look for marginal improvements. And there are those that presume current practices are unsustainable, possibly catastrophic if pursued to their logical conclusions, and that look for alternative forms of social organization.

He then goes on to emphasize the importance of the second and the challenge that it poses:

If the social sciences are going to make a contribution commensurate with the severity of biophysical trends, it must do better than analyze environmental improvement measures. Social scientists must develop analytic tools for the analyst (biophysical and social alike) and an effective vocabulary for the policy-maker and activist that allow, indeed encourage, an escape from well-worn prescriptions that result in marginal change at best).

This paper responds to Princen's challenge. The "well-worn prescription" from which it counsels escape is the current focus on efficiency. The vocabulary put forward reflects an approach to sufficiency which addresses both efficiency and the amount of goods and services consumed in an even-handed fashion. A key feature of the approach proposed is an emphasis on quantification, This provides analytic tools of the sort called for by Princen. The paper argues that widespread adoption of the proposed approach would support more than marginal improvement.

Consideration of the literature on sufficiency raises the issue of quantification. That literature includes descriptions of many efforts to address resource use. Most address usage associated with specific goods or services. Typical of these is a recent discussion of the development of standards for electrical usage by appliances (Calwell, 2010). There have also been economy-wide efforts. For example, interest on the part of an enlightened monarch led to the consideration of the changes that would be required to create a "sufficiency economy" for Thailand (Mongsawad, 2009). All of these efforts encounter a common difficulty: there are no standard procedures for the assessment of their impact. Impact assessment is a critical step in the development and implementation

of policy (Jones, 2011). The existence of standard assessment procedures has facilitated the expenditure of billions of dollars annually on programs to increase efficiency in the use of natural gas and electricity (Barbose et al., 2013). The absence of such procedures for sufficiency is a concern in and of itself. It is also a signpost, pointing to a more basic problem: there is no well-accepted approach to the quantification of sufficiency. As the often-repeated claim that “what gets measured gets managed“ indicates, the importance of quantification is widely recognized (Dickinson, 2009). The introduction to a recent State of the World report makes this point quite forcefully:

For sustainability to have any meaning it must be tied to clear and rigorous definitions, metrics, and mileage markers (Engelman, 2013).

This paper proposes an approach to the quantification of sufficiency. It introduces a metric, describes its structure, and illustrates its use. When considering sufficiency one can adopt a narrow perspective, focusing on resource use associated with a specific good or service, or a broad perspective, taking into account a range of consumption all of which results in usage of the same type. Both perspectives are addressed here. The discussion begins with the development of the proposed approach and metric based on the treatment of end-use efficiency. This is followed by an extended discussion of two specific end-uses -- lighting and automobile use. These examples illustrate the approach and the use of the metric. Once the metric is familiar its relationship to the IPAT equation (Ashford and Hall, 2011) is discussed. The introduction of IPAT provides flexibility in the development and use of the metric which is needed when adopting a broad perspective. Examples involving building energy use and fossil fuel consumption illustrate this point. Building on the foundation provided by the conceptual framework and the examples, the paper concludes with a discussion of action to foster deep societal change.

The approach proposed for the quantification of efficiency is quite general. It can be used to address many types of resource use. However, the examples presented in this paper all focus on energy. This reflects a number of considerations. Energy use is a key driver of climate change, arguably the most important environmental issue facing humanity today. Energy use is well understood and a good deal of data on it is readily available. Once the proposed approach is well understood for energy, it is reasonably easy to see how other types of resource use would be addressed. In this paper the treatment of quantification for sufficiency is not as sophisticated and detailed as that for efficiency today (Wuppertal, 2009). Rather, it is comparable to the early stages of the discussion of efficiency (DOE/EIA, 1995. See in particular Chapter 2).

Two points are addressed throughout this paper. The first is the role that technology could play in efforts to address consumption and its associated resource use. The paper argues that adoption of the proposed approach to sufficiency would increase the opportunities for the use of technology, and that this would likely enhance the effectiveness of the efforts. The second is the ability to address rebound (Herring and Sorrell, 2009). The paper shows that adoption of the proposed approach would provide tools and a strategy for the management of rebound. The paper is brief and it covers a good deal of ground. As one might expect, only a sketch of some points such as the

proposal for action is provided. However, the benefits that would arise from adoption of the proposed approach as a framework and vocabulary and from the use of the proposed metric as an analytical tool are addressed at some length.

Efficiency, Sufficiency and Rebound

There is a well-accepted notion of resource efficiency at the end-use level, that is for an individual good or service. Efficiency improves when a fixed amount of the good or service is provided using less of a resource. This notion leads to the choice of resource intensity -- the number of units of a resource required to provide one unit of a good or service -- as a metric (E) for efficiency. With this choice the resource usage (R) associated with the consumption of a quantity of a good or service (Q) is determined by the efficiency with which it is provided:

$$(1) \quad R = Q \times E$$

In practice (1) provides the basis for the assignment of values to E. This is done using carefully specified units for Q and R and procedures for their measurement.

For a specific good or service one can approach the quantification of sufficiency in the same general fashion as for efficiency. One begins with a quantity of the good or service consumed by a population and the associated resource use. The metric for sufficiency (S) is defined to be the per-capita resource use, that is $R \div P$ where P is the population size. With this definition the metrics for sufficiency and efficiency are closely related. The average per-capita consumption of the good or service (QPC) provides the link between them. Dividing the expression for R shown in (1) by P one obtains the following:

$$(2) \quad S = R \div P = (Q \div P) \times E = QPC \times E$$

The approach to the quantification just described will be referred to as inclusive because the values of the metric reflect both per-capita consumption and end-use efficiency. The inclusive approach is certainly not the only way to quantify sufficiency. The obvious alternative is to treat sufficiency as complementary to efficiency and so use QPC rather than $R \div P$ as its metric. This complementary approach is taken in some discussions of sufficiency (Darby, 2007). It is common in the energy area. The following comment by staff at the Lawrence Berkeley National Laboratory (LBL), one of the leading institutions working in the energy area illustrates its use:

Energy efficiency is not energy conservation. Energy conservation is reducing or going without a service to save energy. For example: Turning off a light is energy conservation. Replacing an incandescent lamp with a compact fluorescent lamp (which uses much less energy to produce the same amount of light) is energy efficiency (LBL, 2013).

As the LBL comment makes clear, in the complementary approach reduction in per-capita consumption (“conservation”) is distinguished sharply from improvement in efficiency. This may be confusing, as the initial sentence in the LBL comment makes all too clear. It can also be prejudicial, as it is in LBL’s linking of conservation to “going without” without consideration of the desirability of the initial consumption level. Turning off lights in a room which feels over lit is an improvement in amenity not a loss.

The inclusive approach to the quantification of sufficiency avoids difficulties of the sort just described. In addition it addresses Princen’s concern with distancing and facilitates the practice of sufficiency as he describes it. The form of the metric -- resource use per capita -- puts the focus on “the consumer,” that is, an individual, household, business or organization, and on the resource use associated with goods and services they consume. The two key decisions that need to be made -- how much of a good or service to consume and how to do so efficiently -- are logically connected, not separated as in the complementary approach. The behavior of the metric sends a balanced signal: the value of S falls when action to either reduce per-capita consumption or improve efficiency is effective. What about societal change? Focusing on sufficiency quantified as proposed here creates an opening to foster societal change. The argument supporting this point is spread throughout the remainder of the paper. However, a crucial step -- recognizing a link between the proposed metric for sufficiency and rebound and using it to frame a general management strategy -- can be addressed now.

A recent survey of the literature on rebound in energy use begins with the following description:

In the most general terms, rebound effect (or take-back effect) is the extent to which the estimated energy savings enabled by the enhancement in energy efficiency are reduced by the behavioral response (i.e., higher consumption) to the increase in efficiency (Gavankar and Geyer, 2010).

One can describe rebound associated with improvements in efficiency for resource use of any type in the same way, simply by replacing “energy” with “resource.” The survey introduces and discusses a number of types of rebound. Direct rebound occurs when an increase in efficiency for a good or service leads to an increase in the consumption of that good or service. As (2) shows, the metric for sufficiency for that good or service picks up the combined effect on resource use from changes in efficiency and consumption on a per-capita basis. The effect on total resource use is captured by $S \times P$. Indirect rebound arises when there is an increase in consumption for goods or services other than the one experiencing the improvement in efficiency. If one can enumerate the goods and services for which consumption changes the metric for sufficiency can be used to capture the combined effect of direct and indirect rebound. Here it is useful to consider a simple example. Assume that two goods or services used by a population involve resource use of the same type. One can decompose the metric for sufficiency for the two taken together into the sum of the metrics for each of them and then apply (2) to each separately as follows:

$$(3) \quad S = \frac{R}{P} = \frac{R_1 + R_2}{P} = S_1 + S_2 = QPC_1 \times E_1 + QPC_2 \times E_2$$

In (3) the subscripts “1” and “2” simply denote the first and second good or service. Now, suppose that efficiency increases for the first. In (3) the resulting change in S will pick up the effect of the change in efficiency in E_1 as well as those from direct and indirect rebound in QPC_1 , and QPC_2 , respectively. (3) can be extended to address any number of the goods or services for which there is indirect rebound.

Recognition of a link between rebound and the value of the metric for sufficiency provides an opportunity to change the way rebound is addressed and its effects are managed. Much of the discussion of rebound in the literature focuses on the estimation of its magnitude often using econometric techniques (Buhl, 2014). Rather than analyzing the operation of rebound in the past, one can look ahead to identify ways in which its effects could be managed. Expressions for the metric for sufficiency such as (2) and (3) provide contexts for decision-making under constraint, with the constraint being a cap on total resource use. So, for example, consider an effort to improve efficiency which is likely to produce direct and indirect rebound. Focusing on (3) one could as part of the effort develop policies and identify actions designed to manage change in QPC_1 and QPC_2 so that after an improvement in E_1 , $S \times P$ will remain below a specified cap. Beyond direct and indirect rebound there is a category that the survey cited above refers to as “economy-wide.” It includes changes in consumption due to efficiency improvements that result from broad shifts such as modifications to the tax code (Frank, 2007). For this type of rebound it is difficult if not impossible to enumerate all of the end-uses for which consumption is affected. However, one can often identify the types of resource use that are affected. One can then focus on managing the behavior of the metric for sufficiency (S) and the associated total resource use ($S \times P$). In the remainder of this paper the process of setting caps on resource use and using them for rebound management in the fashion just described will be referred to as Resource Budgeting.

The ability to manage rebound is a major concern today as it has been in the past (Maxwell et al., 2011). Rebound is often discussed in ways that makes it seem unavoidable (Owen, 2011). But, recently updated modeling based on a very detailed Great Transition (GT) scenario shows that large net reductions in resource use could be accomplished equitably and with a good quality of life world wide (Raskin et al., 2010). However, the GT scenario incorporates major shifts in behavior including greater use of public transit and a less meat-based diet. Over the long run, there is a convergence in income per capita among nations that requires reductions for some (Raskin et al, 2002). As these features of the GT indicate meaningful reductions in resource use will likely require deep societal change involving modifications of well-established habits and practices, changes in norms and aspirations, and possibly shifts in economic and political systems. Recent work such as that on “moral revolutions” shows that dramatic changes in long-established norms, patterns of behavior and institutions have taken place quite quickly (Appiah, 2010). The concern, to which the questions posed by De Young and Princen cited in the introduction direct our attention, is whether humanity will develop

skills and take actions which permit it to live well while remaining “within the limits of this single planet”? Many tools have been developed to understand this challenge and to mount efforts to meet it (Hinton, 2010). The approach to the quantification of sufficiency proposed here is a source of additions to the toolbox. As explained above, carefully specified expressions for the metric for sufficiency provide tools for use in Resource Budgeting. Additional tools useful for this purpose will be developed in the section of this paper that deals with IPAT. The examples presented in the following section and later in the paper will emphasize various aspects of Resource Budgeting. In all of the discussion the focus is on controlling the behavior of sufficiency (i.e., S) with an eye to remaining within a cap on resource use (i.e., S x P). One could, of course, extend the discussion to address efforts to manage population size. Treatment of this important but controversial possibility is left for another time.

A Narrow Perspective

This paper calls for a shift in the way resource use associated with consumption is addressed, moving to an approach based on sufficiency framed in an inclusive fashion. The argument for this shift rests primarily on a series of examples. Those presented in this section adopt a narrow perspective, addressing two specific end-uses -- lighting and automobile use. In a later section examples involving a broad perspective are presented.

The point of departure for the discussion in this section is the metric for efficiency (E). As (1) shows it provides a link between the level of consumption for a good or service (Q) and the associated resource use (R). Somewhat surprisingly, without a need to know how to determine E or even understand the units in which R and Q are measured, this linkage comes into play in daily life. Consider choosing a light bulb. Historically bulbs have been selected based on their labeled wattage (a value of R). What the purchasers cared about was the bulb’s brightness (the corresponding value of Q). As long as the choice was restricted to bulbs that relied on a fixed technology -- simple incandescents, for example -- the bulbs all had the same efficiency. In this situation, tacit reliance on (1) made it clear that brightness and wattage changed proportionately. So, if a 40-watt bulb seemed too dim, it could be replaced with a 60, increasing the brightness by 50 percent. Today things are a bit more complicated. Those replacing a “standard 40” can choose among bulbs that offer the same brightness but draw different amounts of power. To choose among them individuals continue using the metric without knowing it. They fix Q by focusing on “40-watt equivalents.” Then relying implicitly on (1) they use the actual wattage shown on the package as a proxy for the bulb’s efficiency (E). This allows them to compare the different levels of efficiency offered at varying purchase prices.

As the preceding discussion shows, the metric for efficiency provides a framework for a simple task -- the selection of a light bulb. For similar but slightly more complex choices at least tacit use of the framework provided by the inclusive metric for sufficiency soon becomes essential. To see why continuation of the lighting example is useful. Assume that in a home there is a fixture which currently contains a standard 100-watt incandescent bulb. Residents concerned about the resource (i.e., energy) usage

associated with this bulb might reasonably consider changes that involve “conservation” as well as efficiency:

- Replacing the 100-watt bulb with a 75 -- the next lowest in brightness generally available -- reducing the demand and so, all else equal, the electricity used by 25 percent.
- Installing a light-emitting diode (LED) bulb in the fixture, reducing the demand and usage by 85 percent (Pogue, 2013).

For a number of reasons, lowering the wattage should be considered first. It may improve the room’s ambiance. And, installing an LED bulb after deciding to switch to a 75 will increase the reduction in the usage and so the savings in electricity costs. It will also likely reduce the price of the LED bulb. Are the residents likely to give appropriate consideration to the two options? Not if their actions are guided by current public policy. Policy related to lighting is focused on improving efficiency. In many places government is practicing “choice editing,” (Maniates, 2010), simply removing the least efficient bulbs from the market. There are often substantial subsidies offered by government or at its direction to overcome the “sticker shock” created by efficient bulb prices, particularly those of LEDs. However, there is little in the way of encouragement to consider reducing illumination levels. Instead, those seeking guidance on conservation will find comments such as those by the LBL staff cited earlier which link such reductions to “going without.”

The emphasis on efficiency reflects a preference among policy-makers for technology as the source of reductions in resource use. As a recent review article makes clear, there is a perception that efficiency because it is rooted in technology provides more reliable gains while conservation depends on behavior, a less reliable source of improvement (Bachus and Van Ootegem, 2011). In fact, both efficiency and conservation have behavioral aspects. Indeed, in the lighting example, conservation (i.e., switching to a 75) and efficiency (i.e., switching to an LED) both depend on similar changes in behavior. Further, gains which rely on behavior can increasingly make use of technology. To see this consider an additional conservation option as part of the lighting example -- turning the fixture off. Motion-sensing technology in use today routinely operates switches. “Smart” bulbs which can be controlled remotely are on the market today. So, a motion sensor could control a smart bulb in the fixture. Advances, particularly in Information and Communications Technology (ICT), provide increasing opportunities to use technology to obtain what had previously been behavioral gains. Programmable thermostats do that for heating and cooling. Looking ahead, rapid and substantial growth in the use of ICT-based control is anticipated.

The concept of outfitting everyday objects with sensors and connecting them to the web, often called the Internet of Things, has been brewing for several years. But the announcement last week that Google was paying \$3 billion to acquire Nest, a maker of Internet-connected home products, put

a sort of Good Housekeeping seal of approval on this nascent market (Wortham, 2014).

Currently material made available to the public provides information on options such as lighting control technology (U.S. DOE, 2012). However, it does not establish an appropriate framework for using it. Shifting the frame of reference to sufficiency would provide an appropriate framework -- deciding first how much of a good or service such as illumination one wants, and then determining how to provide it efficiently. Efforts based on the inclusive approach to sufficiency proposed here would foster the use of technology to obtain gains from both conservation and efficiency improvement.

Thus far the expression for sufficiency provided in (2) has not entered directly into the discussion of lighting. Instead it has played a hidden role, similar to that played by (1) in bulb selection. This is due in part to a lack of familiarity with the relevant units of measurement among the public. Illumination takes into account brightness measured in lumens and duration measured in hours. The corresponding use of energy is measured in kilowatt-hours (KWH). However, any standard unit for energy will do. Thus, for lighting use of (2) produces the following specific expression for the sufficiency metric.

$$(4) \quad \text{Energy use per capita} = (\text{lumen hours per capita}) \\ \times (\text{Energy use per lumen hour})$$

Looking ahead, changes such as government requirements for better labeling of light bulbs will help bring lumens into more common usage (Federal Trade Commission, 2011). Such improvements in “resource literacy” are important because they will facilitate use of the framework provided by sufficiency.

For now (4) is useful primarily as a basis for quantitative analysis. For example, consider a major shift to use of LEDs. This would provide a substantial reduction in energy use per lumen hour. To what extent might this be offset by an increase in consumption (i.e., more lumen hours per capita)? Following the general approach taken by Saunders and others before him (Saunders, 2013) one can use the framework provided by (4) to develop a long-term historical analysis which provides a useful perspective. Over the period from 1800 to 2000 there were numerous improvements in lighting technology involving shifts from candles to oil, gas, and then electricity. Within each technology there were numerous changes yielding gains in efficiency. A recent volume (Fouquet, 2008) provides data on efficiency and energy use for lighting in Great Britain over the period. Table 1 below shows the results of an analysis based on that data. The top half of the table shows change in each of the terms in (4). The bottom half provides the corresponding change in population and energy use.

**TABLE 1: CHANGE IN ENERGY USE FOR LIGHTING
IN GREAT BRITAIN - 1800 TO 2000
(Ratio of Final to Initial Year Values)**

Efficiency	0.0014
Per-Capita Consumption	10,900.0
Sufficiency	15.3
Population	3.8
Energy Use in Total	58.3

The improvement in efficiency shown in Table 1 is truly dramatic. In 2000 the energy required to provide one lumen hour was roughly a tenth of a percent of that required in 1800. Nevertheless, sufficiency (i.e., the energy used per capita for all sorts of lighting) increased by a factor of over 15 and energy use in total by a factor of nearly 60. This growth took place because per-capita consumption of lumen hours increased by a factor of almost 11,000! How could such an increase have come about? The explanation is quite simple. The shifts in technology which increased efficiency also facilitated consumption. With the move from candles through oil and gas to electricity the ability to easily expand the location and increase the level and duration of illumination changed dramatically. So did the ease and safety of “leaving the lights on” in an unoccupied room, store, office building or outdoor space.

What implications does the historical analysis of lighting hold for us today? In developing nations the availability of lighting remains limited. A recent paper describes a family group of ten in India living in a small space lit intermittently by three incandescent light bulbs (Jackson, 2008). With economic growth one can reasonably expect dramatic increases in the demand for lighting to accompany the use of more efficient technology. And, looking beyond lighting, one is seeing dramatic improvements in the energy efficiency of computing along with increases in energy use in total (Nielsen, 2013). As these examples make clear, today and tomorrow as in the past, direct rebound remains capable of offsetting very substantial gains in efficiency.

Shifting from lighting, the remainder of this section will address a service for which the units arising in (2) are simple and well understood. The service is travel by automobile. To apply (2) P is taken to be the population of a nation or other region; Q the number of miles driven by the automobiles in use in that region; and R the gallons of fossil fuel consumed in the course of that activity. With these choices (2) takes the following specific form:

$$(5) \text{ Fuel Use Per Capita} = (\text{Vehicle Miles per Capita}) \times (\text{Gallons used per Mile})$$

Once vehicle miles are recognized as the unit in which the service is measured it is clear that the first term on the right in (5) is the amount of the service consumed per capita. The second term -- gallons used per mile driven (GPM) -- is the efficiency with which the service is delivered. While all of the units that appear in (5) are familiar the expression

for efficiency is not. In the automotive area discussions of efficiency are generally framed in terms of “mileage,” that is vehicle miles traveled per gallon consumed (MPG) rather than GPM. Does this difference matter? The answer is “yes.”

To appreciate the importance of the way automotive efficiency is framed it is useful to consider a simple example. Table 2 below provides data on various replacements for a “clunker,” that is a vehicle with a poor mileage rating (10 MPG). The replacements considered are another clunker, a “better” used vehicle that gets 20 MPG, a new conventional vehicle that gets 40 MPG, a hybrid that gets 100 MPG, and a “vehicle of the future” that gets 200 MPG. The data in the second and third columns of the table convert the mileage ratings for the replacements shown in the first column into gallons of fuel used and saved per mile traveled. So, for example, if the clunker is replaced by a better used vehicle, fuel use drops from .100 to .050 GPM, resulting in savings of .050 GPM.

TABLE 2: MILEAGE IMPROVEMENT AND ITS EFFECTS

Miles per Gallon	Fuel Use Per Mile	Savings Per Mile	Additional Miles
10	.100	.000	0%
20	.050	.050	100%
40	.025	.075	300%
100	.010	.090	900%
200	.005	.095	1900%

Comparison of the data in the first and third columns of Table 2 makes it clear that MPG is a poor guide to fuel savings. Replacing the clunker with a used vehicle that gets only 20 MPG provides more than half of the fuel savings produced by replacing it with a hybrid that gets 100 MPG (.050 out of .090 GPM). The disparity between the MPG and GPM perspectives is particularly great when one looks ahead. Technical innovations such as the introduction of new lightweight materials make further substantial improvements in mileage a possibility (Lovins, 2012). The increase of 100 MPG provided by a vehicle of the future might seem worth waiting for, even if one is currently driving a clunker and could afford a hybrid. But, as shown in the bottom line of the table, it will add only .005 GPM to the savings of .090 GPM available from the hybrid, an increase of about 6 percent.

If one focuses on the third rather than the first column in Table 2 it becomes clear that in an effort to reduce automotive fuel consumption the emphasis should be on getting the "worst" (i.e., lowest mileage) vehicles out of the fleet even if the mileage achieved by their replacements isn't too much better. Those driving clunkers should not wait until they can afford hybrids. They should purchase better used cars if they cannot afford new and ensure that their clunker leaves the fleet. Today, however, automobile manufacturers and dealers promote the purchase of new vehicles based on high mileage ratings and then, if they can, resell the vehicles taken in trade whatever their mileage (Bunkley, 2012). Adoption of sufficiency as the frame of reference for discussion in the automotive

area would entail a shift from MPG to GPM as the measure for efficiency. Rating new and used vehicles based on GPM would provide considerably better guidance at the time a purchase is made.

Clarity about fuel savings would be reason enough to adopt sufficiency as the frame of reference in the automotive area. However, the benefits don't stop there. There are additional efficiency-related benefits. Proper maintenance and a "smooth" driving style -- avoiding abrupt starts and stops -- can significantly reduce fuel use per mile (Sivak and Schoettle, 2011). GPM is clearly connected to the way a vehicle is cared for and driven. Thus, fostering the practices just mentioned will be easier if the measure for efficiency is GPM rather than MPG. Adoption of sufficiency will also bring conservation, that is actions that lead to a decrease in vehicle miles per capita into consideration. They are not being considered today. Under the heading "The Forgotten Channel" a recent article addresses the treatment of conservation as follows:

The final channel for reductions in oil consumption is reductions in vehicle-miles traveled. U.S. energy policy has largely ignored this channel. Indeed, policies like Corporate Average Fuel Economy standards and biofuel subsidies push in the opposite direction, in the sense that they reduce the marginal cost of driving an extra mile (Knittel, 2012, page 110).

As was the case for lighting a shift to sufficiency would provide a framework for policy development in the automotive area within which efficiency and conservation would be considered in an even-handed, logical fashion.

In the automotive area efforts to foster efficiency and conservation both raise "behavioral" issues. In addressing these issues technology could play an important role. Adoption of a framework based on sufficiency will help that come about. First, consider sufficiency. Today smart dashboards announce the need for maintenance and show MPG on a continuous basis, providing input on the effects of "driving style." After a shift to sufficiency this would continue with MPG replaced by GPM. Because fuel is purchased regularly at considerable expense feedback based on GPM will likely be more effective than that based on MPG. Turning to conservation, a sufficiency-based framework would put achieving it "on the agenda." With that accomplished use of technology would be a natural next step. Internet and cell-phone based services would assist with "careful route selection," that is selection of routes which help minimize fuel use in transit. They would also facilitate ridesharing, fostering improved occupancy and so fewer vehicle miles per capita (Chan and Shaheen, 2010). These uses of technology lessen reliance on behavioral change in achieving gains in efficiency as well as conservation but do not "lock them in." To achieve that one must look to a vehicle of the future, one which can drive itself. Such vehicles will automatically take many of the actions discussed above, locking in choices that enhance efficiency and conservation. In addition they will make tasks such as finding parking much more efficient or avoid it altogether, thereby further reducing fuel consumption (Schmidt and Cohen, 2013).

While MPG is a poor guide to automotive efficiency, data developed using it can be quite useful when considering rebound. In the example under consideration the percentage increase in the MPG for each replacement vehicle compared to the MPG of the clunker is the same as the increase in the miles that each could be driven while maintaining the same level of fossil fuel consumption as the clunker. These percentages are shown in Table 2 in the column headed “Additional Miles.” Their values are substantial. When a clunker is replaced one can expect some direct rebound, that is some increase in vehicle miles driven (Mulligan, 2013). But, experience shows that the size of the direct rebound is likely to be quite modest (Small and Van Dender, 2007). Indeed, recent data indicate that a maximum in vehicle miles per capita may have been reached in some developed nations (*The Economist*, 2012). The disparity between the additional miles that are possible without the purchase of additional fuel and those likely to be driven makes it clear that the replacement of a clunker would generally be accompanied by indirect rebound, that is an increase in the consumption of other goods and services. Of course, “clunker replacement” as depicted in Table 2 refers to a hypothetical situation. However, the issue it raises -- indirect rebound triggered by efficiency gains in the automotive area -- is quite real. Governments are adopting standards that will result in a shift to more efficient vehicles. In the U.S. the government estimates that in 2025 savings of more than \$1.7 trillion in gasoline costs will result from its newly adopted standards (NHTSA, 2012). Savings of this magnitude would lead to substantial indirect rebound and possibly macroeconomic shifts producing economy-wide rebound. To develop tools to manage such rebound effectively the treatment of quantification for sufficiency presented earlier needs to be extended. This extension is the focus of the discussion in the next section.

IPAT

There are a variety of ways to approach the quantification of sufficiency. Instead of building on the notion of end-use efficiency, one can begin with the IPAT equation. This equation is commonly used to express a relationship between an impact associated with human activity (I) and three factors: population (P), affluence (A), and technology (T). IPAT equations can be developed and applied in a variety of ways, some of which raise substantial concerns (Chertow, 2001). One option for development is to require that the relationship expressed be an identity. That is the approach that will be taken here. Based on choices for I, P, and A the equation will take the following form:

$$(6) \quad I = P \times (A \div P) \times (I \div A)$$

$$= P \times (\text{Units of A per capita}) \times (\text{Units of I per unit of A})$$

No matter how I, P, and A are chosen the relationship expressed in (6) is valid because of the way the right-hand side of the equation is structured. The use of (6) here reflects a general strategy -- using carefully specified identities to probe issues of interest -- which is the basis for a substantial amount of economic analysis (Fogel et al., 2013). One might ask why the final term on the right in (6) expresses “technology.” The notion is that it is the choice of technology that determines the impacts associated with affluence.

To use (6) to address sufficiency it is useful to rearrange it a bit. Dividing both sides by P produces the following expression:

$$(7) \quad I \div P = (\text{Units of A per capita}) \times (\text{Units of I per unit of A})$$

If one specifies for the impact resource use associated with consumption of some sort, the form taken by (7) is as follows:

$$(8) \quad \text{Resource Use Per Capita} = (\text{Units of A per Capita}) \\ \times (\text{Resource Use per Unit of A})$$

On the left side of (8) one has the metric for sufficiency introduced earlier. On the right one has a decomposition of the metric similar to but more general than that provided in (2). Sufficiency is expressed as per-capita affluence times the intensity of resource use per unit of affluence. The choice of the measure for affluence determines the specific factors which appear. Consistent with the general strategy mentioned above, the art in using (8) lies in making “good” selections for R and A. This use of (8) is the basis for the discussion of examples that reflect a broad perspective in the next section. In the remainder of this section ability to vary A is used to develop an expression for sufficiency which is useful in addressing rebound.

One can use IPAT to reproduce the expression for the metric for sufficiency for a specific good or service developed earlier in this paper. The quantity of a good or service consumed by a population (Q) is a measure of their affluence. With A replaced by Q the terms on the right-hand side of (8) become the expressions for QPC and E, transforming it into (2). Building on that observation can introduce the average price for the good or service (U) and take A to be the expenditure on the good or service (U x Q) rather than the quantity consumed. This choice leads to a new decomposition.

$$(9) \quad S = \frac{R}{P} = \frac{U \times Q}{P} \times \frac{R}{U \times Q} = \frac{U \times Q}{P} \times \frac{R}{Q} \div U \\ = \text{PCE} \times (\text{E} \div U)$$

In (9) the first term on the right (PCE) is the per-capita expenditure on the good or service. While it may not be immediately apparent, the second (E ÷ U) is the resource use per unit of expenditure.

(2) and (9) emphasize different aspects of sufficiency. (2) provides a “physical view,” (9) a “monetary view.” One can use (9) to recast analyses that initially reflected the physical view. To see how this works it is useful to return briefly to the “two-service” example that arose in the discussion of indirect rebound in the section before last. Assume that two goods or services entail resource use of the same type. The value for the metric for sufficiency for the two taken together (S) is the sum of the values for the two

taken individually (S_1 and S_2). Applying (9) to S_1 and S_2 one can rewrite (3), the expression for the metric for the two services developed earlier, as follows:

$$(10) \quad S = PCE_1 \times (E_1 \div U_1) + PCE_2 \times (E_2 \div U_2)$$

As in the earlier discussion assume that there is an improvement in efficiency in the first service, leading to direct as well as indirect rebound. Resource Budgeting, the strategy for managing rebound introduced earlier, involved setting a cap for $S \times P$ and then managing consumption (i.e., the values for Q_1 and Q_2) to stay below it. Using (10) one can modify the approach, managing the expenditures -- PCE_1 and PCE_2 -- rather than the physical quantities. The advantage in using (10) rather than (3) to budget is simple: (10) involves only resource use and money, (3) involves the possibly obscure units in which goods or services are measured. Focusing on expenditures highlights the possibility that in practicing Resource Budgeting, it may not be possible to spend all of the available income. This provides a link to the emerging discussion of degrowth and, more generally, the “New Economics” (Brown et al., 2013). Finally, going beyond rebound (10) suggests a general strategy for resource management -- to the extent possible shift expenditures to goods or services with low values for $E \div U$.

In this paper the discussion of IPAT is focused on its use in the quantification of sufficiency. It emphasizes the development and analysis of expressions for S because these are central to Resource Budgeting and to resource management more generally. However, the introduction of IPAT also opens the door to various elaborations of the analysis of resource use and its impacts. Going back to (6), one can add a factor -- emissions per unit of I -- to both sides of the equation. This leads to the well-known Kaya identity which provides the starting point for much of the modeling of greenhouse gases and other emissions (Rosa and Dietz, 2012). In a similar fashion, one can add factors to (6) that address “quality of life” (Von Weizsäcker et al., 2009. See Figure 11.1.). The discussion here lays a foundation for both sorts of elaborations. Indeed, examples presented in the next section show how consideration of quality-of-life issues and environmental impacts arises naturally from the proposed approach to the quantification of sufficiency via the use of IPAT.

A Broad Perspective

The examples involving residential lighting and travel by automobile discussed earlier in this paper illustrated ways in which consideration of the metric for sufficiency and its structure as shown in (2) can be useful in the effort to manage rebound. One can apply (8) in the same general fashion as (2), to address the management of rebound in examples that reflect a broad rather than a narrow perspective on sufficiency. The use of (8) requires two choices: the type of resource use (R) and the measure of affluence (A). The examples presented in this section illustrate both of them. The examples continue the discussion of ways to achieve gains in efficiency while managing rebound and so control resource use and its impacts.

The first example to be considered focuses on building energy use at the national level, addressing residential and commercial buildings separately. The measure for affluence is taken to be the total floor space in each subsector. While this may initially seem an odd choice, its use is standard. With building energy use by subsector as the choice for R and A as indicated (8) takes the following form:

$$(11) \quad \text{Building energy use per capita} = (\text{Square footage per capita}) \\ \times (\text{Energy use per square foot})$$

(11) provides a framework for quantitative analysis. Using it, one can examine the extent to which population growth together with, changes in floor space per capita and the intensity of energy use per square foot have contributed to change in building energy use in each subsector. Table 3 shows the results of such an analysis based on U.S. data for 1984 to 2004 (U.S. DOE, 2008).

**TABLE 3: CHANGE IN BUILDING ENERGY USE
IN THE U.S. - 1984 TO 2004
(Percent)**

	----- Actual -----		Modified For
	Residential	Commercial	Both Subsectors
Intensity	-10	12	-19
Floor Space Per Capita	20	8	0
Sufficiency	8	21	-19
Population	24	24	24
Energy Use	34	50	0

The first two columns in Table 3 show the historical experience in the two subsectors. Those in the first column tell a simple story. Over the period considered the intensity of energy use per square foot in residential sector buildings fell, but not enough to offset the growth in floor space per capita. As a result, the metric for sufficiency -- building energy use per capita -- increased. This increase together with population growth resulted in rising energy use. The story for the commercial sector differs a bit in the details. The growth in sufficiency reflects increases in both floor space per capita and intensity. However, the “bottom-line” result is the same as for the residential subsector -- energy use increased substantially. Using the framework provided by (11), one can develop modifications to the historical data that would have allowed energy use in both subsectors in 2004 to remain at 1984 levels. These are shown in the final column of the table. Zero growth is used here simply for illustrative purposes. However, looking back, it or even a substantial reduction in energy use is not hard to justify (Porter, 2013). To achieve Zero growth while keeping the population increase at 24 percent sufficiency would have needed to fall by 19 percent. To produce this reduction in sufficiency the modified case removes any increase in floor space per capita and assumes an

improvement in intensity of 19 percent. As with Zero growth, this choice of modifications is simply illustrative.

Comparison of the actual data with that in the modified case highlights the challenges that the Resource Budgeting would have faced in meeting a Zero-growth goal. For both subsectors the modified case departs from historical experience in floor space growth. The addition of ever-larger residential units has been the trend for some time in the U.S. (Glaeser and Gyourko, 2008). This would have had to change. Avoiding growth in floor space per capita is not an objective that resource policy has typically addressed. Intensity is where policy has usually focused. Intensity reflects three factors: the mix of end-uses, the amount of service taken from each, and the efficiency with which the service is provided. Within intensity it is efficiency that typically provides the primary policy focus. To address mix and service levels, the actions of building occupants would need to change. Unfortunately there is a lack of linkage between building efficiency and the actions of the occupants. Recent research on a sample of residential sector buildings makes this point quite clearly:

In a recent study that monitored extended energy use patterns in a community of retrofitted Zero Energy Homes (i.e., houses with zero net annual energy consumption and carbon emissions), results showed that while the energy efficient and energy generating features of the buildings were effective in reducing the net energy consumption of these dwellings, the patterns of occupational energy use by inhabitants remained the same as the patterns of their neighbors living in conventional homes (Velikov et al., 2013).

Another paper, this time addressing the commercial sector shows that the behavior of the building occupants can tip the scales, overcoming the beneficial impacts of building efficiency:

Technological progress may reduce the energy demand from heating, cooling, and ventilation, but the behavioral response of building tenants and the large-scale adoption of appliances more than offset these savings, leading to increases in energy consumption in more recently constructed, more efficient structures (Kahn et al., 2013).

As the results in Table 3 indicate, in an effort to address intensity the commercial subsector would have been of particular concern. A shift from growth of 12 percent to a decline of 19 would likely have required substantial change in all three factors.

Above and beyond the challenges considered thus far, there is rebound to contend with. Suppose that the changes in intensity and floor space shown in the modified case had been achieved for both subsectors. This would have lowered energy usage and so costs substantially. And, energy is just the tip of the cost reduction iceberg. Smaller houses are generally less expensive, so average mortgage costs for new homes would likely have fallen as well. So would the amount of money required to pay for commercial

construction. The additional discretionary spending by consumers and business triggered by achieving the modified case would likely have been massive. If the reduction in energy use -- the goal in pursuing the modifications -- were not to be offset this spending would need to have been carefully managed and perhaps much of it avoided altogether.

The stark contrast between the historical data and the modified case presented in Table 3 highlights a point made in the previous section -- the depth of the societal change required for meaningful reduction in resource use. Writing more than a decade ago Duane Elgin described the sort of change that is required:

I believe that we will need to make major changes in every aspect of our lives -- including the transportation we use, the food we eat, the homes and communities we live in, the work that we do, and the education we provide. Although it is appealing to think that marginal measures such as intensified recycling and more fuel-efficient cars will take care of things, they will not. We need to make sweeping changes -- both externally and within ourselves. A sustainable future will demand far more than a surface change to a different *style* of life -- it requires a deep change to a new *way* of life (Elgin, 2000. Emphasis in the original.).

The approach to sufficiency proposed in this paper provides a framework within which standard sources of data can be used as they are in Table 3 to assess progress or lack thereof in reducing resource use. Exercises of this sort highlight areas such as floor space growth and appliance mix and patterns of usage on which policy might focus. While such information is essential it is not likely to be sufficient to foster the required change. There also needs to be evidence that pursuit of deep societal change of the sort described by Elgin is a reasonable choice. Somewhat surprisingly, quantification of sufficiency is useful in addressing that need as well. The next example illustrates this point.

The next example to be considered focuses on fossil fuel use for combustion at the global level. This choice reflects the importance of such combustion as a source of GHG emissions, an inherently global concern. It provides a broad perspective which includes automotive fuel use discussed earlier. The key point addressed in this example is the specification of A and particularly the effects of change in that specification. The initial option considered is Gross Domestic Product (GDP). With it (8) takes the following specific form:

$$(12) \quad \text{Fossil Fuel Use per Capita} = (\text{GDP per capita}) \times (\text{Fuel Use per } \$ \text{ GDP})$$

The use of GDP is standard practice in national and global level energy accounting. The reasons for this become apparent as one examines the terms on the right in (12). The first term -- GDP per capita -- is generally referred to as Income. This terminology reflects the fact that GDP can be expressed as the sum of wages, rents, profits, interest, etc. (BEA, 2007). All of the components of Income are ultimately spent to purchase goods and services. With this in mind Income is often used as a generalization for per-capita consumption of a specific good or service. Building on this use of Income the expression for intensity that appears in (12) -- fossil fuel use per dollar

of GDP -- is used as a generalization for end-use efficiency in the development of data on energy use (International Energy Agency, 2008).

Following the general approach taken with (11), (12) can be applied to examine change in the use of fossil fuel for combustion. Drawing on global-level historical data and a well-known set of projections (Maddison, 2007) the first two columns in Table 4 show the results of such an examination. The data in the first column show that from 1973 to 2003 there was improvement in intensity (i.e., a reduction in fossil fuel combustion per dollar of GDP). However, that improvement was more than offset by growth in Income. As a result, the metric for sufficiency -- fossil fuel use per capita -- increased by about 7 percent. In combination with population growth this produced a substantial increase in the total amount of fossil fuel used for combustion. Looking ahead, Maddison projected a continuation of the historical pattern. As indicated in the second column growth in Income continues to more than offset improvement in efficiency, causing the metric for sufficiency to rise by 5 percent. Combined with population growth, this produces an increase of 36 percent in the fossil fuel used for combustion by 2030.

**TABLE 4: CHANGE IN FOSSIL FUEL COMBUSTION
AT THE GLOBAL LEVEL
(Percent)**

	----- GDP Based -----		GPI-Based 1973-2003
	1973-2003	2003-2030	
Intensity	-33	-42	7
Income/Welfare	59	81	0
Sufficiency	7	5	7
Population	60	30	60
Fossil Fuel Use	70	36	70

As Maddison makes clear, his projections are based on "business-as-usual" assumptions. Those uncomfortable with the projected growth in fossil fuel combustion can respond by calling for action that produces greater than anticipated improvement in intensity. But, with population and Income growth of 30 and 81 percent respectively, keeping fossil fuel combustion in 2030 at the same level as in 2003 would require a reduction of roughly 23 percent in intensity on top of the 42 percent improvement in Maddison's projections. Such an additional improvement will likely be accompanied by a substantial reduction in fuel costs and so by increases in spending leading to massive rebound. One might also call for action to reduce the growth in Income. However, adopting policies designed to foster lower Income growth is a leap not a step into the new way of life called for by Elgin. The final column in Table 4 presents the results of an analysis that supports taking such a leap.

Thus far in this section the choices for A have simply reflected "standard practice." Beyond that rationale there is a crucial difference between the two choices.

Floor space per capita reflects a relevant physical aspect of a building energy system. GDP is simply an accounting measure. There is an extensive literature critical of its use (Stiglitz et al., 2010). And there are other accounting measures such as the Global Progress Indicator (GPI) that can be used in its place (Talberth et al., 2006). In particular GDP can be replaced by GPI in (12), providing a new framework for analysis. The final column of Table 4 shows the result of using recently developed data on the historical behavior of GPI (Kubiszewski et al., 2013) in place of data on GDP to recast the historical analysis presented in the first column. The results in the initial and final columns tell quite different stories. Between 1973 and 2003 there was a substantial increase in Income. In contrast, the level of GPI per capita remained essentially unchanged over the period. This difference is important because GPI per capita was designed to measure welfare related to economic activity. GDP per capita wasn't and it doesn't (Coyle, 2014). Using GDP there is a substantial decline in intensity. With GPI there is a modest increase. In both cases the "bottom line" remains the same -- substantial growth in fossil fuel use for combustion. The improvement in intensity reflects the choice to use GDP, not progress in addressing fossil fuel use.

During the historical period covered by Table 4 the current global market economy was born and rose to dominance. The data developed using GPI indicate that its emergence was accompanied by increases in fossil fuel combustion and its associated adverse impacts, but not by any gain in material welfare. This long-term "lose-lose" experience together with more recent developments, particularly the real estate bubble and financial market crash (Stiglitz, 2012), creates an opening for serious consideration of alternative economic approaches (Schor, 2010 and Stutz, 2011), approaches which support adoption of the practice of sufficiency as Princen describes it. Adoption would in turn foster changes in basic attitudes that guide life in today's market economy:

- In the market economy the choice of what to consume is seen as a private decision based on individual preferences. Sufficiency in Princen's framing is an "ethic for sustainability" which inherently reflects a societal perspective.
- As Adam Smith famously explained, operation of the market economy rests on individuals acting to maximize personal gain. The practice of sufficiency entails "doing well by doing a bit less than the most possible." This requires a rejection of maximization.

Of course, adverse developments provide only an opening. The next section takes up the issue of action to foster deep societal change and support its success. But, before turning to action, it is useful to pause for a moment to build a bit on the example under discussion.

In the discussion of fossil fuel use for combustion the essential step was the consideration of the two measures for global affluence. One can use these same choices for A in an analysis of the behavior of the Ecological Footprint (FP) at the global level. The Footprint measures our use of a resource, bioproductive land area, to provide food and materials and to absorb waste. Consideration of the Footprint may seem a substantial departure from fossil fuel combustion. But in reality the two are closely related. It is the

increasing size of the area required to absorb atmospheric carbon, carbon produced largely by fossil fuel combustion, that accounts for most of the growth in the Footprint (Winkler and Galli, 2012). Table 5 below was constructed using data on the Footprint provided in the presentation just cited. The time period for the analysis is the same as that in Table 4, permitting the use of the data from that table for the change in population, Income and Welfare (i.e., GPI per capita).

**TABLE 5: CHANGE IN THE ECOLOGICAL FOOTPRINT
AT THE GLOBAL LEVEL - 1973-2003
(Percent)**

	GDP Based	GPI Based
Intensity	-47	-16
Income/Welfare	59	0
Sufficiency	-16	-16
Population	60	60
Footprint	35	35

In the results shown in Table 5 both intensity and sufficiency improve (i.e., their metrics decline). This is true using either GDP or GPI as the measure of affluence. However, the Footprint still increases substantially. When all is said and done what is of primary interest is the behavior of resource use in total. The historical behavior of the Footprint makes this very clear. In 1973 nearly all the bioproductive land was utilized. By 2003 the Footprint had grown to exceed the capacity of the earth by roughly 30 percent. Thus, growth in the Footprint should have been avoided entirely. Taking a bottom-line perspective one sees that improvements in the behavior of sufficiency and particularly of intensity can be misleading. As the results in Table 5 indicate the substantial historical improvement in sufficiency was simply not enough. To keep the Footprint at its 1973 level the improvement would need to have been about 38 percent, more than double the 16 percent achieved. The apparently very substantial improvement in intensity shown in the first column turns out to reflect the choice of GDP as the measure for affluence, not the behavior of the Footprint. Use of GPI rather than GDP cuts the improvement by about two-thirds.

Into Action

Thus far the focus in this paper has been on the development of tools, particularly expressions for the metric for sufficiency such as (2), (3), (8), and (9) and their use in analyses of examples presented in Tables 1 to 5. Now the focus shifts to actions that, building on the foundation the tools and analyses provide, would help foster deep societal change of the type described by Elgin and called for in the questions asked by De Young and Princen. Three actions are discussed:

- Establishment of an ongoing public conversation about the level of usage for key resources.

- Expansion of education to provide information about well-being and to develop knowledge and skills required to manage resource use.
- Development of ICT-based applications that would facilitate the practice of sufficiency.

These are certainly not the only actions that could be taken. However, taken together they do provide a reasonable start on an effort to foster societal change.

In a recent volume focused on global warming Anthony Giddons introduced the notion of Foregrounding and explained the rationale for it as follows:

Given its potentially cataclysmic implications, we need global warming to be a front-of-the-mind issue; however, both in the political sphere and in the minds of citizens, it all too readily becomes a back-of-the-mind one. Foregrounding refers to the use of the various political devices that can be deployed to keep global warming at the core of the political agenda (Giddens, 2011, page 73).

Giddens assigned primary responsibility for Foregrounding to government. What Giddens said concerning global warming is true for a range of resource use that has significant adverse environmental impacts. This point was recognized by Diane Coyle in her discussion of action to foster a shift to an “economy of enough” (Coyle, 2011). To address it she proposes that government conduct an annual Measuring Progress Exercise, publish the results and make them the focus of ongoing serious discussion. Conduct of such an exercise is the first action proposed here. The exercise would be framed based on the notion of sufficiency proposed in this paper.

When considering Giddens’ call for Foregrounding and Coyle’s proposal for a Measuring Progress Exercise, an initial question is whether government will take such an active role. Despite a lack of public support governments have in the past pushed forward with progressive change in a number of areas (Newman and Jacobs, 2010). That said, it is likely that government will find it a challenge to take the lead as Giddens and Coyle propose. However, government could develop Sufficiency Accounts which building on current efforts provide the data required for a Measuring Progress Exercise. While the development of these accounts would involve many technical challenges, the general approach is fairly easy to describe. Key resources would be identified and measurement conventions for them would be established. Recent work on Planetary Boundaries provides a natural starting point for this effort (Rockström et al., 2009). For each key resource national-level data on usage would be developed with an eye to making it useful in analyses based on sufficiency. Data on usage for major categories as well as important specific goods and services would be broken out. Recent research provides guidance on how to structure this break-out process (Tukker et al., 2008. See figure 1.1 and the accompanying discussion.). To complement the information on resource use data on population, QPC for important goods and services and various choices for A -- PCE, GDP, GPI, square footage, etc. -- would be provided. All of the data development would be based on a harmonized approach similar to that used to produce Standard National

Accounts (U.N., 1993). This would permit the national-level data to be combined to produce multi-national and global level information. Development of harmonized environmental/economic data has been discussed for some time (Bartelmus et al., 1991).

Using the Sufficiency Accounts the Measuring Progress Exercise would be conducted at regular intervals. The exercise would have a “top-down structure.” It would address the consumption of each key resource and its most important components, emphasizing actual use compared to “safe levels” such as those specified in the Planetary Boundaries analysis. A recent paper (Gerst et al., 2013) shows how the Boundaries can be integrated into this sort of an analysis. A primary goal for the exercise would be to make the consequences of what Elgin refers to as our current “way of life” harder to evade. To that end the exercise would use information in the accounts to examine the story we tell our self about our efforts to manage the use of key resources. Tables organized in the same fashion as those in this paper would highlight important aspects of the various types of resource use and the choices that influence them. Going beyond a critique of resource use there would be a discussion of evidence that deep societal change is desirable. Material similar to that in the last column in Table 4 and the accompanying discussion would be part of the exercise. Finally, there will need to be one or at most a few easy-to-understand, “headline” indicators which summarize the results of the Measuring Progress Exercise. The Footprint is one possible choice. But, alone it lacks the breadth required. Once the scope of the Measuring Progress Exercise is clear, the parties responsible for it can “custom build” the desired indicator(s) (Stutz, 2013).

Coyle argues that it would be desirable to have government take the lead in the conduct of the Measuring Progress Exercise and in the discussion of its results. This is true but only if it is capable and willing to undertake a serious ongoing endeavor. If not, a group of Non-Governmental Organizations (NGOs) with a wide range of support might be the better choice. If the exercise is an NGO effort it will be important to include whatever governmental support can be had for the notion that resource use has significant impacts. Information providing such support is in fact on offer today. The U.S. government documents the substantial growth in the nation’s energy use, links that growth to increases in Carbon Dioxide (CO₂) in the atmosphere, and provides information on the connection between emissions of Greenhouse Gases such as CO₂ and a variety of impacts (U.S. EPA, 2012). Other governments provide similar information. Inclusion of results from analyses that compare societal benefits and costs arising from activities that require extensive resource use may also be useful. For example, consider the impact of U.S. agricultural exports on public health. A recent article in *Science* compares the benefits and the costs from ammonia emissions as follows:

Although the health toll varies greatly by location, the burden is heaviest in cities, because of the concentration of NO_x and people. And the total impact is eye-opening: about \$100 per kilogram of ammonia, or \$36 billion annually. In contrast, the net value of the exported food is \$23.5 billion (Stokstad, 2014).

Stepping back from the technical details, the key issue here is Foregrounding. No matter who sponsors it, a Measuring Progress Exercise will not be adequate. Complementary actions are needed to make use of key resources and its impacts a permanent “front-of-the-mind concern.” The additional actions proposed here were chosen with an eye to the necessary complementarity.

The second action proposed is change in the educational system, expanding the curriculum to address well-being and introducing activities to cultivate interest and build skill in the management of resource use. The notion that well-being should be a focus for public education is not new (Noddings, 2003). Looking ahead, education needs to address the well-known weak linkage between Income and satisfaction with life as well as the less well-known, strong linkage between “selfless action” and gratification (Seligman et al., 2004). In particular the adverse impacts that follow from a tight focus on material and economic success need to be addressed (Kasser et al., 2004). Education of this sort would help shift public discourse. Today the notion that there might be substantial change in the economy motivated by an interest in greater well-being is not under discussion, but it needs to be raised. Education concerning well-being would provide a shared basis for this discussion. The more radical notion of sacrifice is part of the discussion among those concerned about the environment (Maniates and Meyer (eds.), 2010). Eventually this notion needs to become part of a broader public discussion. Education concerning well-being would help pave the way for this to happen.

Even without addressing well-being, education could make a significant contribution to deep societal change by addressing the management of resource use. It could help create the familiarity and develop the skills required to make management successful through the use of specially designed computer games. A recent report has identified game-based learning as an important recent development and described the games in use as follows:

Most games that are currently used for learning across a wide range of disciplines share similar qualities: they are goal-oriented; have strong social components; and simulate some sort of real world experience that students find relevant to their lives (Johnson et al., 2012).

There are games available today that address complex resource-related concerns (SolidWaste.com, 2013). Development of games which focus on the management of resource use and have the qualities cited is certainly possible. An educator who has studied the role of games has noted that they can help the users “prepare for action” (Gee, 2007, p. 80). If the “resource games” are interesting enough they would be used in school and out. Were this to occur a portion of the substantial out-of-school activity that computer games elicit would be focused on learning how to reduce resource use, rather than how to steal cars and wage war.

The final action proposed is the development and promotion of ICT-based applications (“apps”) which facilitate the practice of sufficiency. Today doing so is not a pressing concern. An attitude-action gap (Newton and Meyer, 2013) arises from this lack of pressure and is compounded by the complexity of the task. Success in practicing

sufficiency will require access to and effective use of a large amount of data. Fortunately, the ability to utilize Big Data effectively is becoming a hallmark of our age. Emerging capabilities can be brought to bear, allowing decision-making that reflects a substantial level of detail and sophistication to become common practice (Einav and Levin, 2013). Today apps help users to find the best prices for air travel and secure accommodations quickly and efficiently. Similarly, apps can facilitate consumption decisions that respect resource constraints. At the cutting edge today are apps that go beyond providing assistance when it is requested. A recent article describes their operation as follows:

A new type of mobile app is departing from a long-standing practice in computing. Typically, computers have just dumbly waited for their human operators to ask for help. But now applications based on machine learning software can speak up with timely information even without being directly asked for it (*Technology Review*, July/August 2013, page 66).

Apps of the type just described could be quite helpful in bridging the attitude-action gap which might otherwise considerably reduce the extent of Resource Budgeting among those who wish to adopt this practice.

The use of games and apps is part of a broader, ICT-based approach to the challenges posed by resource management which has been addressed throughout this paper. As a recent volume (Thompson, 2013) explains, this approach has had notable success in addressing other complex tasks:

- In the wake of man vs. machine contests a new form of chess has emerged. In it players combine their gaming skills with their ability to use a computer. In the world of chess “man/machine collaboration” has raised the average level of play and the pace of individuals’ progress significantly.
- Determining the way protein molecules are folded is important in medical research. Using the Internet researchers made software which simulates folding freely available to non-scientists. This triggered a collaborative online effort involving 200,000 participants which rapidly led to the solution of problems which had been outstanding for a decade.

Of course, there is no guarantee that an ICT-based approach to resource management and the practice of sufficiency will attract the interest or have the success seen with chess or the folding of molecules. However, as the volume cited notes, experience is providing insight into the features of ICT-based efforts that stimulate interest and contribute to success.

Summing Up

This paper takes the notion that “what gets measured gets managed” seriously. Thus, in an effort to foster adoption of sufficiency as the framework for consumption decisions, it emphasizes quantification. The metric proposed for sufficiency -- per-capita resource use -- makes consumers of all sorts and their choices the center of attention. Adoption of an inclusive approach to quantification brings “conservation” into a policy discussion which is currently focused on efficiency. As the discussion throughout this paper shows, substantial use of technology can make it a more reliable source of gains than it has been in the past. The examples presented in the paper show that massive improvements in efficiency are required to achieve reasonable levels of resource use. Such improvements raise concerns about rebound. Resource Budgeting, a technique based on the proposed approach to sufficiency, provides a means by which that rebound can be managed. The proposed metric for sufficiency supports the development of tools for that purpose.

Building on the framework, tools and examples presented, this paper puts forward an initial plan of action. Development of Sufficiency Accounts and their use by government or others in an annual Measuring Progress Exercise provides a starting point for a serious effort to live within ecological limits. The results of the exercise together with education concerning the determinants of well-being would over time provide a basis on which increasing numbers might choose “doing well by doing a bit less than the most possible” as a way of life. Educational games and widely available ICT-based apps that address consumption decisions would support this choice. Ideally over time there would be an increasingly detailed Measuring Progress Exercise, more and more realistic educational computer games, and an increasing selection of apps that facilitate the task of Resource Budgeting, all based on a common set of Big Data resources. This would be an important step in an effort to foster deep societal change. There is no guarantee that the desired change will follow from this effort, but it is a reasonable hope.

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