The Multifaceted Nature of Sustainability Challenges: An Engineering Perspective

The Multifaceted Nature of Sustainability Challenges

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ABSTRACT

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KEYWORDS

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Acknowledgments

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CHAPTER 1

Introduction

Let's begin with a story. Once upon a time, a king was challenged to a game of chess by a poor farmer. If he lost, the king would have to pay the farmer a chessboard's worth of grain, defined as one kernel of grain on the first square, two grains on the second square, four grains on the fourth square, and so on, with each subsequent square receiving double what was on the previous square. The king accepted the wager but, because this is fable, lost the game. A chessboard has eight rows and eight columns, so the king had to pay 264 (less one) grains of rice. Since it takes seven thousand grains of rice to make a pound (65 mg each), the king owed her 1.195 exograms (one exogram is 1015 kg), which is about 12% of the weight of everything ever produced by the human species [1]. At US$6.85/bushel, the grain would be worth about 300 trillion dollars, which is (roughly) ten times more money than exists in the world.

This story, which goes back at least until the 1200s, illustrates several aspects of the sustainability problem that have been evident for centuries. Exponential growth is not sustainable. Big numbers are hard to grok. It's not OK to take giant risks.

The purpose of this book is to summarize the evidence that humans are not living sustainably and to show the characteristics of sustainable societies. The choices and paths to sustainability are bristling with value judgements and moral choices. This book attempts to provide a coherent framework for discussing sustainability that is grounded in a sense of scale. Each chapter is short, with focused discussion questions at the end of each chapter. The questions, which mostly focus on tradeoffs, do not have "right answers," instead, different answers are indicative of different preferences. Basic data and key concepts start each chapter. This book is not comprehensive; the intent is to equip readers with basic knowledge (informed by scale) so we can grapple with tough moral questions. We intend the book to be easy to read but hard to digest.

The remainder of this chapter will summarize key themes of the book. Sustainability is existentially important but very difficult for humans to achieve, for several reasons. The numbers and timescales involved are difficult for humans to grasp for a variety of reasons. Sustainability challenges are complex because they involved a variety of interrelated problems from different domain areas. The challenges associated with transitioning to a sustainable existence are complex and interconnected. It is the intention of this book to explore the challenges of sustainability. While we may, at times, point to directions for improved sustainability, it is beyond our scope (and indeed our ability) to provide solutions for all sustainability problems.

1.1 WHAT IS SUSTAINABILITY?

Are humans living "sustainably?" If not, we will – at some point – either cease to exist as a species or (at least) experience drastic reductions in our standard of living. Thus, the question of sustainability is of utmost importance. There are many answers to this question. To the novice, many answers may seem to indicate lack of agreement. However, sustainability is almost a self-defining concept. Different answers indicate different assumptions, different priorities, and different boundaries (that is, what is the system under consideration).

When considering the meaning of sustainability, the two most important questions are "sustaining what?" and "for how long?" The second of these questions is perhaps easier to answer. While humans seem to have difficulty planning for time scales significantly longer than the human lifespan, true sustainability is achieved only if the answer is "indefinitely" or "forever." The narrowest answer for what needs sustaining is human life and society, which perforce entails those ecosystem services necessary for human health and wellbeing. Beyond these basics, some people view the nonhuman world as having inherent worth or standing and, as such, to also be worth preserving, even if it has no (or negative, for example, smallpox) impact on human continuity. Unfortunately, humans don't know clearly what pieces of the ecosystem are, in the long run, necessary for survival and which aren't. For instance, would we be able to survive in a world without dandelions? Maybe. On the other hand, dandelions might be necessary for other organisms we depend on. Environmental science views the ecosystem in its entirety as a web, with all parts depending on all other parts. The ecosystem is viewed then, not as individual components with binary "needed" "not needed" classifications but as a whole that exists on a continuum from "fully functional" to "nonfunctional." The choices and paths to sustainability are bristling with value judgements and moral choices. How much risk do you think is appropriate? What do you value preserving? Different answers to these questions come from different a priori assumptions and values.

The broadest definitions of sustainability include human-created devices and systems. Humanity could survive without the great pyramids of Giza, although we would have lost great cultural and historical artifacts. On the other hand, we may not survive if we don't give up coal-fired power plants. Thus, the Three Pillars of sustainability are its environmental, economic, and social aspects. Environmental sustainability considers biophysical and thermodynamic constraints and includes issues such as pollution, resource depletion, habitat loss, and biodiversity. Economic sustainability involves questions of profit and loss, wealth management, and macroeconomic policy. Social sustainability comprises human and civil rights, suffering, and personal freedom. This book will discuss issues associated with each of these three areas of sustainability but with a focus on energy and carbon emissions because it is not the only sustainability problem, just the one that needs to be solved most urgently.

The most oft-quoted definition of sustainability comes from the Brundtland report "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Note that sustainable development (an oxymoron?!) is not the same as sustainability and "needs" are subjective.

Herman Daly proposed the following three rules for achieving ecological (or environmental) sustainability:

1. Renewable resources such as fish, soil, and groundwater must be used no faster than the rate at which they regenerate.

2. Nonrenewable resources such as minerals and fossil fuels must be used no faster than renewable substitutes for them can be put into place.

3. Pollution and wastes must be emitted no faster than natural systems can absorb them, recycle them, or render them harmless.

The core idea is that [the rate of] human impact on the ecosystem can be no greater than the ecosystem can absorb, which introduces the idea of the capacity of the ecosystem to provide resources and "take care of" wastes. We will examine the idea of capacity in greater detail in the next chapter.

1.2 IMPACTS AND THEIR SOURCES

Two mathematical expressions, IPAT and Kaya have been used express human impact on the environment and its sources. IPAT expresses "impact" on the environment as the product of human population, affluence, and technology. The Kaya identity is a form of the IPAT equation but limits impact to CO2 emissions. Kaya also helpfully expresses the generic "technology" as the product of energy intensity of the economy and the carbon intensity of energy.

The first section of this book is organized around a combination of the IPAT and Kaya approach. We keep the general "impact" of IPAT but use the more helpful expression of technology from Kaya.

$$Impact = Population \times Affluence \times Resourceintensity \times Contaminationintensity \tag{1.1}$$

Impact is a vector quantity (that is, a list) including such things as global warming potential, aquifer depletion, and eutrophication potential. Population is the (scalar) number of people in the world. Affluence is the world per capita GDP. Resource intensity is the vector or list of resources necessary to produce one unit of world GDP. Lastly, impact intensity or contamination intensity is a matrix that lists the impacts of each type of resource.

IPARC is true because it is an identity, and it will provide a useful organizing framework for the following chapters. The terms are equilibrium values, that is they represent static, or steady-state levels, but do not give completely useful information about how changes in any one variable will affect the others. For instance, using resources more efficiently (improving resource intensity), does not lower impact. Instead, it leads to more affluence (see chapter 5). Likewise, it may not be possible to drive the impact(s) per unit of resource to zero because of diminishing returns on efficiency and tradeoffs that exist between different types of impacts.

1.3 THE MATHEMATICS OF SUSTAINABILITY

Returning to the wheat and chessboard problem, for a series of doubling numbers, like the number of grains on a chessboard square: $1, 2, 4, 8, 16, 32, \ldots$, the sum of all the numbers in the series is always one less than the next number in the series. $1 + 2 + 4 + 8 = 15$, which is one less than 16. $1 + 2 + 4 + 8 + 16 = 31$, which is one less than 32.

Extending the doubling on discrete squares or in discrete time to continuous time is exponential growth. Things that grow exponentially double in a fixed amount of time. An example with a negative growth rate is radioactive decay, where the corresponding time is called the half-life because the amount of time for half of the radioactivity to decay away is constant. When growth rate is constant, the amount of time to double is approximately 70 divided by the growth rate. With a fixed 3% growth rate, GDP doubles every 23 years. If your investment portfolio has a 7% return, your assets will double every 10 years.

In the discrete case, like the wheat and chessboard, the next square is always one more than the sum of all the previous squares. In the continuous case, the amount in the next period (B) is always 1.71 times the sum of all previous amounts (A). The result for sustainability is that the resources needed by the economy in the next 23 years – for instance, energy – will be more than the total resources (energy) used in all of history. Populations are modeled as having constant growth rates. We actively manage the economy have a constant growth rate (say a target of 3% GDP growth per year). Because of (exponential) growth in population and affluence, humanity is not on a sustainable path.

1.4 CO2 AND ENERGY

The approach above (IPARC) is general in that all kinds of impacts can be considered. In this book we will consider many types of impacts and many kinds of sustainability (environmental, economic, and social). However, our focus – in the chapters – is mostly on energy use and CO2 emissions. Reasons for an energy/CO2 focus include the availability of data and that we feel it is (currently) the most urgent sustainability problem. End-of-chapter discussion questions tend to focus more on social aspects of sustainability and worldview issues.

CHAPTER 2

Planetary Boundaries

CHAPTER 3

Population

CHAPTER 4

Affluence

CHAPTER 5

Energy intensity of the economy

CHAPTER 6

Carbon intensity of energy

CHAPTER 7

Households

CHAPTER 8

Transportation

CHAPTER 9

Agriculture

CHAPTER 10

Land use and urban planning

CHAPTER 11

Government

CHAPTER 12

Personal action

Bibliography

[1] Matthew Kuperus Heun, Michael Carbajales-Dale, and Becky Roselius Haney. *Beyond GDP: National Accounting in the Age of Resource Depletion*, volume 26 of *Lecture Notes in Energy*. Springer International Publishing, New York, 2015. URL http://dx.doi.org/10.1007/978-3-319-12820-7.

[2] David Paul Warners and Matthew Kuperus Heun. *Beyond Stewardship: New approaches to creation care (forthcoming)*. Calvin College Press, Grand Rapids, Michigan, 2019.

Author's Biography

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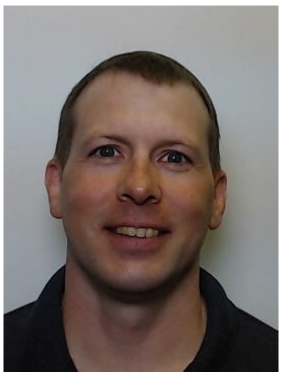
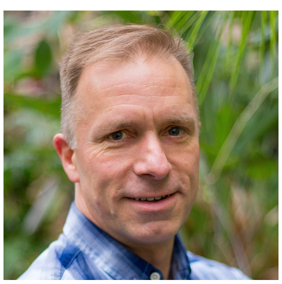


Jeremy Van Antwerp earned a Ph.D. in chemical engineering from the University of Illinois at Urbana-Champaign. More text here.

MATTHEW KUPERUS HEUN



Matthew Kuperus Heun is Professor of Engineering (mechanical concentration) at Calvin University in Grand Rapids, MI, USA. He earned an M.S. and Ph.D. in mechanical engineering from the University of Illinois at Urbana-Champaign and later worked at NASA's Jet Propulsion Laboratory and at Global Aerospace Corporation. He has been a visiting scholar at the Centre for Renewable and Sustainable Energy Studies at the University of Stellenbosch, South Africa. His long-term research question is "What is the relationship between energy and the economy when viewed through the lens of sustainability?" In addition to scores of articles, he is lead author of *Beyond GDP: National accounting in the age of resource depletion* [1] and a co-editor of *Beyond Stewardship: New approaches to creation care* [2].