Numeracy
Advancing Education in Quantitative Literacy

Volume 15 | Issue 2 Article 4

2022

An Introduction to *A Framework for Sustainability Thinking*

Jeremy Van Antwerp
Calvin University, jva@calvin.edu
Matthew Kuperus Heun
Calvin University, mkh2@calvin.edu

Recommended Citation
Van Antwerp, Jeremy, and Matthew K. Heun. "An Introduction to *A Framework for Sustainability Thinking*." *Numeracy* 15, Iss. 2 (2022): Article 4. DOI: https://doi.org/10.5038/1936-4660.15.2.1423

An Introduction to *A Framework for Sustainability Thinking*

Abstract

Van Antwerp, Jeremy and Matthew Kuperus Heun. 2022. *A Framework for Sustainability Thinking*: *A Student's Introduction to Global Sustainability Challenges*; (Springer, Cham) 275 pp. ISBN 978-3-0317-9184-0.

A Framework for Sustainability Thinking: *A Student's Introduction to Global Sustainability Challenges* presents basic information related to sustainability challenges in the context of a cognitive framework that allows students to evaluate problems and potential solutions from a quantitative perspective. Moreover, numerous end-of-chapter discussion questions and project ideas examine moral, ethical, and worldview aspects of sustainability choices and tradeoffs between different approaches to sustainability.

Keywords

sustainability, energy, systems thinking

Cover Page Footnote

Jeremy Van Antwerp is a professor of engineering at Calvin University. He holds one U.S. patent and is the lead author of *Identification and Control of Sheet and Film Processes*. His poetry, cartoons, and puzzles have appeared in *IEEE Control Systems*.

Matthew Kuperus Heun is a professor of engineering at Calvin University. In addition to scores of articles, he is the lead author of *Beyond GDP: National Accounting in the Age of Resource Depletion* and a co-editor of *Beyond Stewardship: New Approaches to Creation Care* .

Arguably, sustainability is the most important issue that humanity faces. If human society is not sustainable, the long-run consequences will be dire for humanity and, perhaps, all other life on this planet. Although the world faces many sustainability challenges, climate change caused by human greenhouse gas emissions is the most important and urgent. All sustainability challenges, including climate change, are multifaceted and interdisciplinary, making sustainability itself both challenging to teach and difficult to learn.

We teach an introductory, one-credit seminar course on the many interrelated sustainability challenges humanity faces. The course is open to any first-year university student. The student learning objectives include (1) learning basic facts about sustainability, (2) comprehending the interdisciplinary nature of sustainability challenges, and (3) evaluating sustainable practices and technologies.

We were dissatisfied with lecture-based pedagogy for achieving the learning objectives. Instead, we envisioned a course structured around an easily comprehended text that would teach "facts and figures" in an engaging way to achieve the first learning objective. We could then devote (precious) class time to discussing "big ideas" about sustainability to achieve the second and third learning objectives.

We wrote a new textbook (*A Framework for Sustainability Thinking: A Student's Introduction to Global Sustainability Challenges*) to support the course objectives with our desired pedagogy. The textbook gives students new to the field of sustainability a cognitive framework for how to organize, compare, and evaluate sustainability challenges. Extensive end-of-chapter questions and projects enable classroom discussions and facilitate opportunities for deeper analysis. Students read the text on their own, outside the classroom, to obtain basic information related to sustainability challenges. A basic and straightforward quiz on the reading holds students accountable. Students should prepare for class discussion by reviewing end-of-chapter questions. With the support of discussion questions, class meetings can be devoted to exploration of *a priori* value judgements and the importance of sustainability relative to other challenges facing humanity, such as poverty, racism, and international conflict.

Although the book solves a specific problem for a particular course, we believe it will be helpful for anyone interested in sustainability because it introduces the many challenges of sustainability and provides a framework for thinking about the topic. The book could be used in any setting that prioritizes discussion, like a book club or a small group. Individual chapters, or sets of chapters, will be appropriate for a wide variety of group structures, types, and levels.

This book makes four main contributions:

(1) Basic facts, figures, and information related to sustainability. Readers will gain a sense of scale for sustainability challenges, that is, which things are big and important and which are smaller and less relevant.

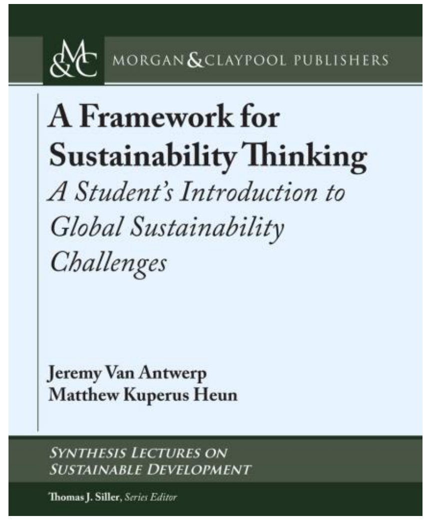
(2) An explanatory framework for thinking about sustainability, primarily in Chapters 1–6. The IPARX identity (a version of the Kaya identity) provides scaffolding and structure for readers.
(3) A wealth of end-of-chapter discussion questions that address moral, ethical, philosophical, and practical aspects of sustainability. Few questions have objective answers. Rather, they illustrate the importance of worldview, values, preferences, and *a priori* assumptions for each person's approach to sustainability.
(4) Inspiration for future sustainability-related inquiry and study. The end-of-chapter projects range in scope from a long homework problem to a graduate thesis. Instructors can use one—or perhaps more—of the projects for semester-long or capstone assignments, with optional in-class presentations.

The book is organized in three sections. Chapters 1–6 comprise Part I. The first chapter is an introduction. Each of the next five chapters focuses on one term in the IPARX equation: human impacts (*I*), population (*P*), affluence (*A*), resources (*R*), and the impact of resource extraction and consumption (*X*). Part II (Chapters 7–10) explores the reasons why we face these challenges in several topical areas: housing, transportation, agriculture, and land use. The areas selected are based, in part, on where energy is consumed. Part III (Chapters 11–12) examines individual and collective actions for sustainability. By the end of the book, readers should see that sustainability entails important, urgent, and difficult challenges; that sustainability transitions are needed; and that everyone can play a role in helping the world become more sustainable through a variety of individual and corporate actions.

The book excerpts below illustrate its contributions. Section 1.1 provides context, presents the overall structure of the text, and highlights the book's data-driven nature. Section 1.3 presents a version of the Kaya identity called the IPARX equation, which is the organizing framework for the text. This section notes important caveats about the IPARX equation, namely that it is static and does not explain relationships among the variables. Nevertheless, we use it as a lens through which the field of sustainability can be examined. Section 5.5 is an example of the "basic facts and figures" about sustainability and includes application of the IPARX framework to aid comprehension. Lastly, we present a few discussion questions and projects from Chapter 5 to illustrate their contribution to the text. On average, 16 discussion questions and 8 projects support each chapter.

Excerpt from *A Framework for Sustainability Thinking*

1.1 Purpose and Focus



[Available from Springer Link]

This book summarizes ways that humans are not living sustainably and suggests characteristics of sustainable societies. The text is deliberately short because the book is not intended to be comprehensive. The focus is on equipping the reader to discuss moral and ethical issues around sustainability. Because the choices and paths to sustainability are filled with value judgments and moral choices, the end-of-chapter discussion questions mostly point to tradeoffs and do not have "right answers." Instead, different answers indicate different preferences. This book presents a coherent framework for discussing sustainability that is grounded in a sense of scale. Therefore, we prioritize presenting information graphically. The intent is to equip readers with basic knowledge (informed by scale) so we can grapple with tough moral questions. *This book should be easy to read but hard to digest.* As you read this book, it should raise many questions for you.

The focus of this book is the many challenges of sustainability. While we may, at times, point to directions for improved sustainability (Chapters 11 and 12), it is beyond our scope (and indeed our ability) to provide solutions for all sustainability problems. Some (or many) of the questions that are raised about sustainability will remain unanswered.

Our framework for describing sustainability challenges is illustrated by data. Thus, readers can expect graphs, tables, and other numerical representations of the state of our world as it relates to sustainability. Part I (Chapters 1–6) shows mostly data from the world in aggregate, thereby eliminating issues of imports and exports between countries. Part II shows data mostly from the U.S.,[1] because it is our home country and because it has better data coverage than most countries regarding energy and carbon emissions. Behind the facts and data are important concepts

[1] Readers are encouraged to remember that the U.S. is atypical in many ways. Sociologically, the U.S. is WIERD (Western, industrialized, educated, rich, and democratic). Additionally, the U.S. has a low population density and lots of resources. While our framework for sustainability thinking is universal, the data used for illustration may not always apply to the rest of the world.

related to human choices, which we explore throughout the book, mostly in questions and projects that follow each chapter.

The remainder of this chapter summarizes key themes of the book.

…

1.3 A Framework for Environmental Sustainability Thinking

Two mathematical identities, **IPAT** and **Kaya**, have been used to express the impact of human activities on the environment. IPAT expresses "impact" (I) on the environment as the product of human **population** (P), **affluence** (A), and technology (T). The Kaya identity is a form of the IPAT identity but restricts environmental impacts (I) to CO_2 emissions (I_{CO_2}). On the other hand, Kaya expands the generic expression for "technology" to be the product of **primary energy intensity** of the economy (R_{Ep}, energy per unit of gross domestic product, GDP) and the **carbon intensity of energy** (X_{CO_2}, CO_2 emissions per unit of energy).

Chapters 2–6 of this book are organized around a hybrid of the IPAT and Kaya approaches. We keep the more general "impact" of IPAT but also generalize the expanded "technology" expression from Kaya as the product of **resource intensity of the economy** (R) and the **impact of resources** (X).

$$\underset{\text{Impact}}{I} = \underset{\text{Population}}{P} \times \underset{\text{Affluence}}{A} \times \underset{\text{Resource intensity of the economy}}{R} \times \underset{\text{Impact of resources}}{X} \quad (1.1)$$

$$\left[\frac{\text{impact}}{\text{year}}\right] \quad [\text{persons}] \quad \left[\frac{\$\text{ GDP}}{\text{person}-\text{year}}\right] \quad \left[\frac{\text{resouces}}{\$GDP}\right] \quad \left[\frac{\text{impact}}{\text{resources}}\right]$$

In the **IPARX** formulation, impact (I) is a list of impacts (that is, a vector quantity) that includes such things as **global warming potential (GWP)**, aquifer depletion, and eutrophication potential. Population (P) is the number of people in the world. Affluence (A) is GDP per capita per year. Resource intensity of economic activity (R) is the list (vector) of all the resources necessary to produce one unit of world GDP. Last, impact of resources (X) is a list of the impacts of each type of resource. (That is, X is a matrix quantity.)

In broad strokes, sustainability can be seen in the I term (environmental impacts) and in resource extraction (the numerator of R and the denominator of X). If we emit wastes at a rate greater than can be assimilated by the environment (I too large), we are unsustainable. If we withdraw resources from the environment at a rate greater than their regeneration rate, we are unsustainable.

DOI: https://doi.org/10.5038/1936-4660.15.2.1423

> The IPARX identity is a static relationship. Its terms represent steady-state levels, but do not necessarily show how changes in any one variable affects the others. For instance, using resources more efficiently (improving resource intensity), does not, in general, 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. Thus, while Equation (1.1) is useful as a conceptual framework for thinking about sustainability challenges, it does not provide a complete roadmap for sustainability solutions (in part) because of interactions among the terms.

IPARX is true because it is an identity, and it provides a useful organizing framework for the following chapters. To illustrate the IPARX framework, energy and CO_2 are prime examples in the rest of the text, because energy is the master resource and climate change is our most urgent sustainability challenge. Of course, the two are closely linked.

…

5.5 Energy Intensity of the Economy (R_{Ep})

Continuing the explication of the IPARX identity, one piece or facet of resource intensity of the economy (R) is the primary energy intensity (R_{Ep}) of the world economy. R_{Ep} is the amount of primary energy required to create one unit (dollar) of world GDP. Of course, many other resources are also required to create a unit of GDP, but we use energy as the prime example of an important resource in the economy. The primary energy intensity of the economy is formed by dividing primary energy consumption (E_p) by world GDP, that is, dividing the regions of Figure 5.6 by the line in Figure 4.2. The result is Figure 5.9.

Figure 5.9 shows that the primary energy intensity of the world economy (R_{Ep}) has fallen from 15 to 4 MJ/2017 international dollar across the last two centuries. The decline is caused by the fact that the world economy's GDP (Figure 4.2) has been growing at a faster rate (in %/yr terms) than primary energy consumption (Figure 5.6). The decline indicates that each additional dollar of GDP is created with incrementally less primary energy consumption.

While the decrease in R_{Ep} (the prime example for R in Equation (1.1)) appears to be good news for sustainability (declining R puts downward pressure on I in Equation (1.1)), Figure 5.9 shows that the most important cause of decreasing primary energy consumption per unit GDP is declining consumption of biomass.

Ironically, the decreases in R_{Ep} are coming from reduction in per-GDP consumption of a type of energy that is possibly sustainable, biomass!

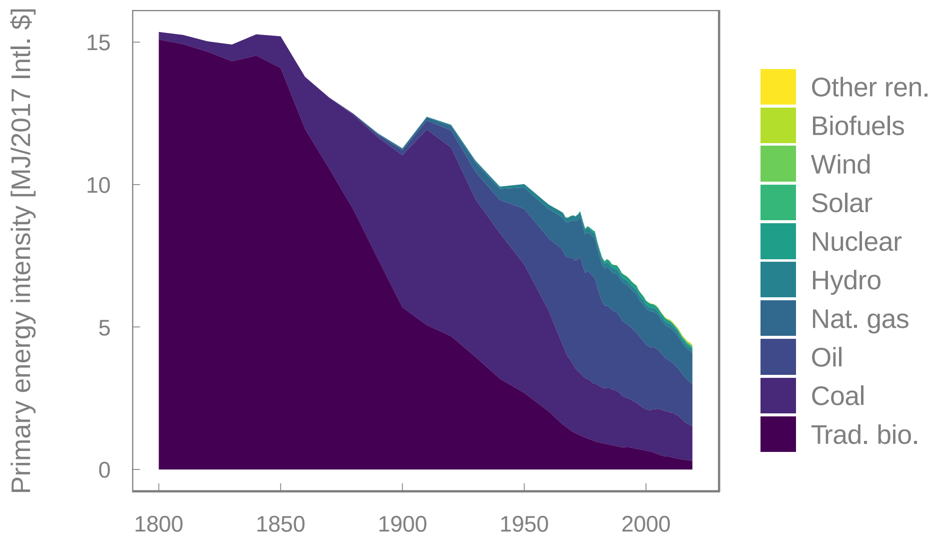


Figure 5.9. Primary energy intensity of economic activity (R_{Ep}) vs. time by energy type. R_{Ep} is the prime example for R in the IPARX identity, Equation (1.1). The line represents the ratio of the lines in Figures 5.6 and 4.2.

We can use these data to learn things about the IPARX terms (Equation (1.1)) and CO_2 emissions. A narrowed version of Equation (1.1) considers only CO_2 emissions on the left-hand side of the equation (I_{CO_2}) and the energy intensity of economic activity (R_{Ep}) instead of R on the right-hand side. When R_{Ep} falls, downward pressure is placed on CO_2 emissions. Whether CO_2 emissions actually decrease depends on the rates of increase or decline of the other terms on the right side of Equation (1.1). Figure 2.5 shows that CO_2 emissions have been growing over time. So, other terms on the right side of the IPARX identity must be growing collectively faster than energy intensity of the economy is declining; see Section 6.5.

…

Questions

Q5.1 Some aquifers, such as the Ogallala aquifer, are called “fossil water” because they were filled with glacial melt from the last ice age. Is using any such resource sustainable? What are the moral and ethical implications of leaving a valuable and usable resource unused?

…

Q5.6 Time is our most constrained resource. The human lifespan is about 4000 weeks. How do you use your time? What fraction of your total time is devoted to economically productive activities? Why? What are the sustainability impacts of how you spend your time? Can you quantify the sustainability impacts of how you spend your time in terms of the IPARX identity?

Q5.7 Where does your water come from? How does it get to you? Where is your wastewater treated? How is energy, the master resource, involved in each of these steps? How has water provision changed over time where you live?

…

Q5.9 Carbon-driven global climate change and population growth are making desalination of seawater a more prominent source of water for many populations. Carbon emissions from desalination may increase from 76 million tonnes of CO_2 per year in 2015 to 200–500 million tonnes per year by 2040 (Global Clean Water Desalination Alliance).

(a) Is there an individual right to water?
(b) Do nation states have a right to water?
(c) Does it matter if you're oil-rich Saudi Arabia or the (relatively) poor and low-lying Republic of the Marshall Islands?
(d) Discuss how these rights impact global efforts to limit climate change.

…

Projects

P5.8 Evaluate the ecological and economic impacts of substitution of an injection-molded plastic part for a stamped steel part on an automobile. What are the raw material and extraction implications? How much energy is used to create the part? Does using a lighter part have energy implications over the life of the vehicle? Are there issues with corrosion or UV exposure? Are there disposal or recycling issues? In your view, which material is more environmentally friendly? Where do you get data to answer these questions? Where do you draw boundaries? How do you evaluate tradeoffs?

P5.9 In winter, fresh food is transported from warm locations (for example, California and Florida) to cold locations (Michigan, for instance), consuming fossil fuels and causing CO_2 emissions. Alternatively, LED lighting could be used at indoor farms to grow food in cold climates in the winter. Assess the benefits and drawbacks of the LED approach relative to the shipping approach. When would it make sense from a sustainability point of view to grow locally using LEDs? When is it more sustainable to transport food from warm to cold climates?

P5.10 Research the efficiency of electricity generation and distribution. How are line losses as well as the efficiency of power generation (from coal or natural gas) quantified? What is the efficiency of natural gas extraction and distribution? Be sure to account for the amount of gas leaking from pipes and storage facilities. Which method of delivering energy to the consumer (electric lines or gas pipelines) has the greatest efficiency (energy/energy)? Which has the least emissions (kgCO2e/MJ delivered)? Which is most cost effective? Are there other considerations that should influence the choice of which type of energy to use, such as reliability, energy storage, or suitability for a particular application?

References

Global Clean Water Desalination Alliance. 2015. “H2O minus CO2” concept paper. *Technical Report*.

DOI: https://doi.org/10.5038/1936-4660.15.2.1423