Matthew Kuperus Heun
Mik Carbajales-Dale
Becky Roselius Haney

25 January 2015

Nikita Dhiwar
Rajdeep Roy
Springer
India

Dear Nikita and Rajdeep:

This document is part of zip file named “BeyondGDP_2015-01-25.zip”. Unzip that file to obtain author corrections to the proofs that you sent on 20 January 2015. You’ll find:

- The file named “Notable PDF Export - 978-3-319-12820-7_Book_ProofPDF_with_index_2015-01-25T12h10.pdf” which includes our suggested changes to the manuscript as annotations within the PDF file itself,
- This document which contains many suggested changes that are supplemental to the annotations in the PDF file, and
- A folder named “Updated figures” that contains .pdf versions of updated figures for the book.

Please ensure that your editors find and work with all three sources of corrections: annotated PDF file, additional information below, and the “Updated figures” folder.

Thank you very much for working with us on this title. Please let us know if you have any questions.

Sincerely,

Matthew Kuperus Heun (for Mik and Becky)

Authors' Addresses:

Please ensure that the address changes provided in comments on the first page of metadata are reflected in metadata for all chapters.

Abstracts:

The *Revised Abstracts.txt* file that was sent with the submitted manuscript was not incorporated into the proofs that we received. The abstract for each chapter in the author proofs is incorrect and must be replaced with the associated text listed under "Abstract Meta-Data" at the end of this document.

Footers on 1st page of each chapter:

Please replace “M. K. Heun, et al.” with “Heun, Carbajales-Dale, and Haney”

Reference Style:

It is possible that we do not understand the Springer style for references. But, the proofs seem to be inconsistent. Within the text, citations have been (mostly) included before periods. E.g., “Carpenter [1].” For mottos and block quotations, citations have been (mostly) included after periods. E.g.e, “Carpenter. [1]”. Please ensure that all citations follow the Springer style.

Abbreviations (Fig., Eq., etc.)

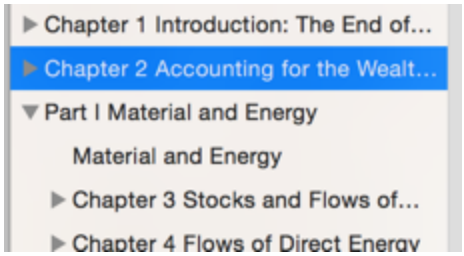
We have highlighted some instances where a sentence begins with a term which in other places has been abbreviated. An example comment in the PDF would be “Figure xx shows that” → “Fig. xx shows that”. We’re unsure of the Springer style on this matter. If sentences that begin with reference to a figure, section, equation need to have the word spelled out instead of abbreviated, please ignore our comments suggesting otherwise.

PDF metadata for document outline, navigation, bookmarks:

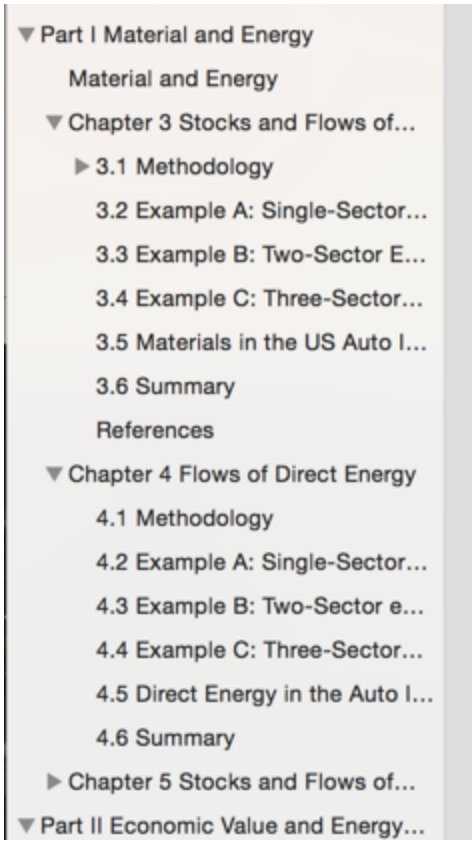
We noticed many problems with hyperlinking and the outline in the PDF document. Furthermore, page numbering in the PDF outline does not match manuscript page numbers.

The following comments apply to the PDF outline and hyperlinks in the PDF file.

Remove "Material and Energy" between "Part I Material and Energy" and "Chapter 3..." in the PDF outline:

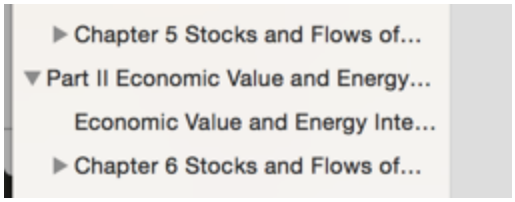


Add item for Chapter 4 References section in PDF outline. Note that References for chapters 1, 2, and 3 are included in the PDF outline.



Add item for Chapter 5 References section in PDF outline

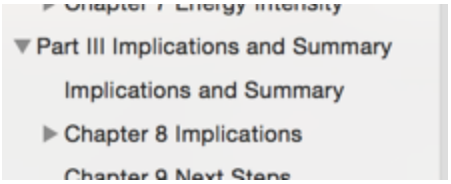
Remove "Economic Value and Energy Intensity" between "Part II..." and "Chapter 6..."



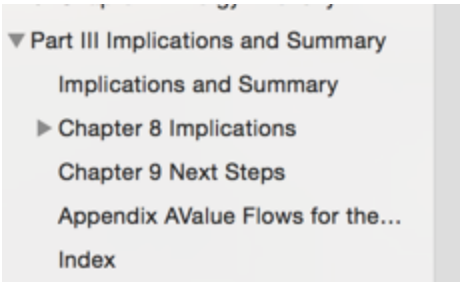
Add link to Chapter 6 References section

Add link to Chapter 7 References section

Remove "Implications and Summary" between "Part III..." and "Chapter 8..."



Add item for Chapter 8 References section in PDF outline
Add item for Chapter 9 References section in PDF outline
Move "Appendix A..." up a level out of Part III



Add space between A and V in "Appendix AValue Flows..."
Add items for the following sections to the PDF outline. Note that the appendices are NOT in Part III. They should be at the top level of the PDF outline.

- Appendix A References section
- Appendix B
- Appendix C
- Appendix D
- Appendix E
- Appendix E References section
- Glossary
- Bibliography

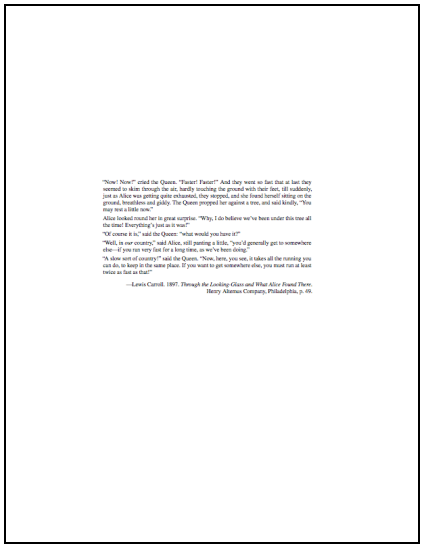
Sort out where the Index should be included. There are 4 entries for Index!

Remove "321388..." and all its children from the PDF outline.

Motto formatting:

The Red Queen quotation at the beginning of the book looks awful in the proof. Please format it as we submitted (see below):

Red queen, full page



"Now! Now!" cried the Queen. "Faster! Faster!" And they went so fast that at last they seemed to skim through the air, hardly touching the ground with their feet, till suddenly, just as Alice was getting quite exhausted, they stopped, and she found herself sitting on the ground, breathless and giddy. The Queen propped her against a tree, and said kindly, "You may rest a little now."

Alice looked round her in great surprise. "Why, I do believe we've been under this tree all the time! Everything's just as it was!"

"Of course it is," said the Queen: "what would you have it?"

"Well, in our country," said Alice, still panting a little, "you'd generally get to somewhere else—if you ran very fast for a long time, as we've been doing."

"A slow sort of country!" said the Queen. "Now, here, you see, it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!"

—Lewis Carroll. 1897. *Through the Looking Glass and What Alice Found There.* Henry Altemus Company, Philadelphia, p. 46.

Chapter mottos:

We prefer the following formatting for chapter mottos.

- Motto in italics
- Citation NOT italicized
- Author NOT italicized
- Author right justified.

See below for the example from the version we submitted. Please use this formatting for the motto for every chapter.

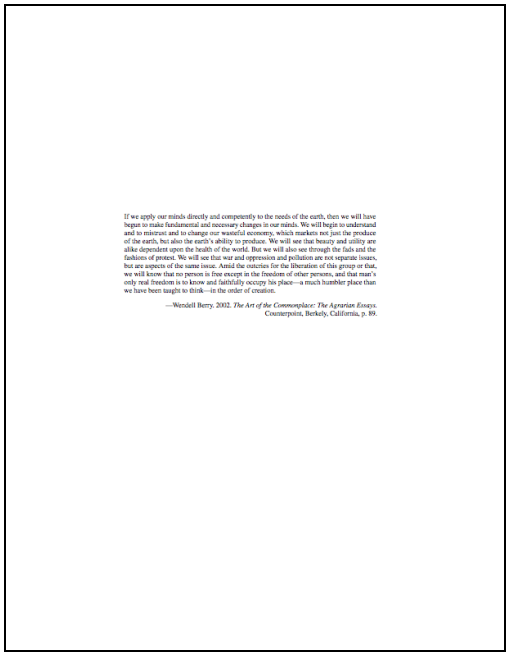
Prologue

The economic light is brightest under the lamppost of the market, but neither drunks nor statisticians should confine their search there. In extending the accounts, we must endeavor to find dimly lit information outside our old boundaries of search, particularly when the activities are of great value to the nation. [1, p. 23]
—William Nordhaus

One of the first calls for integrated and comprehensive reporting of environmental-economic data, including natural and manufactured capital,[1] came from the Brundtland Commission (1983–1987), which recognized the need to devise rigorous methods for integrating environmental assets into national balance sheets and income

The Wendell Berry quotation that ends the book should be typeset on its own page as we submitted. In the author proofs, TWO copies of this quotation were included, neither were on its own page. See below for our preferred formatting.

Wendell Berry full page:



Citations:

Add hyperlinks to citations in Preface and Prologue

Add hyperlinks from table of contents to each part, chapter, and section of the book.

Footnote markers:

Add hyperlinks to all footnote markers in main text. This will be very important for the pdf version of the e-book.

Clickable links:

We would like to add hyperlinks to all references to Citations, Figures, Tables, Equations, Sections, Chapters, and Parts. We have attempted to provide comments for all instances where the hyperlinks is missing. But, we may have missed some. Please perform a detailed search for each reference to a bibliographic item, figure, table, equation, section, chapter, and part and add hyperlinks.

New or Updated Figures (in attached zip file):

Several figures need to be changed for formatting consistency, inability to obtain copyright permissions, or other factors. We have attached a .zip file with new versions of the figure. Please make the following adjustments to the figures:

Fig. 1.5 - replace with “Conventional_Oil_new Graphs_3.pdf”.

Fig. 1.5 - New caption: “Slowing growth in world oil supply. Data from [xxxx, Figure A.2, p. 274].”

For [xxxx] citation in Fig. 1.5 caption, use this reference:

```
@phdthesis{Dale:2010aa,
        Address = {Christchurch, New Zealand},
        Author = {Michael Anthony Joseph Dale},
        School = {University of Canterbury},
        Title = {{Global Energy Modelling: A Biophysical Approach (GEMBA)}},
        Year = {2010}}
```

Fig. 1.6 - delete. Unable to obtain copyright permission.

Fig 3.1 - replace with PERKS_basic_unit_materials.pdf

Fig 3.3 - replace with PERKS_basic_unit_materials_recycle.pdf

Fig 3.4 - replace with 2_sector_materials.pdf

Fig 3.5 - replace with 3_sector_materials.pdf

Fig 4.1 - replace with PERKS_basic_unit_energy_content.pdf

Fig 4.2 - replace with PERKS_basic_unit_energy.pdf

Fig 4.5 - replace with 3_sector_direct_energy.pdf

Fig 4.6 - replace with PERKS_basic_unit_energy_auto_ind.pdf

Fig 5.1 - replace with PERKS_basic_unit_embodied_energy_content.pdf

Fig 5.4 - replace with 3_sector_embodied_energy.pdf

Fig 5.5 - replace with PERKS_basic_unit_embodied_energy_content_auto_ind.pdf

Fig 6.1 - replace with PERKS_basic_unit_value_with_biosphere_flows.pdf

Fig 6.2 - replace with PERKS_basic_unit_value_all_3.pdf

Fig 6.3 - replace with PERKS_basic_unit_value.pdf

Bibliography (at end of book):

Remove numbers from references. This should be an alphabetical listing of all references. Numbering is unhelpful, even confusing.

For example,

~~2. Allwood JM, Cullen JM, Carruth MA, Cooper DR, McBrien M, Milford RL, Moynihan MC, Patel AC. Sustainable materials: with both eyes open. UIT Cambridge Limited; 2012~~

should be changed to

Allwood JM, Cullen JM, Carruth MA, Cooper DR, McBrien M, Milford RL, Moynihan MC, Patel AC. Sustainable materials: with both eyes open. UIT Cambridge Limited; 2012

We have provided annotations in the PDF file to fix references sections at the end of each Chapter. Please recompile the full Bibliography from these annotations.

Index:

We have checked through the index information for letter A (comments in pdf). There are some pages of the manuscript where index terms appear but are not included in the index. Please check again for index terms. Because the index may change due to repagination from changes in text, we ask that Springer handles the indexing.

Significant changes in text:

There are two places where we request significant changes to the text.

p. 15:

Replace this paragraph:

~~The challenges of energy substitutions are highlighted when examining the financial situation of oil producers. Figure 1.6 shows that despite the recent increase in oil production rate and continued high prices, the free cash flow[15] of independent oil producers is negative. This situation implies that capital investments are unproductive to date. It remains to be seen how independent producers can continue advancing the oil production rate (which implies capital investment) while their free cash flow is negative. One possible cure for negative free cash flow is higher oil prices. But higher oil prices will lead to increasing energy cost share, and we saw in Sect.1.3.1 that high energy cost share provides recessionary pressure.~~

with this one:

The challenges of energy substitutions are highlighted when examining the financial situation of oil producers. The EIA indicated in July 2014 that the free cash flow[15] of oil producers was negative, despite the increase in oil production rate and (at the time) continued high prices [citation A]. In the second half of 2014 oil prices fell, and several articles confirmed the earlier EIA report of financial difficulty for oil producers and their financiers [citations B, C, and D]. This situation implies that capital investments are unproductive to date at current oil prices. It remains to be seen how oil producers can continue advancing the oil production rate (which implies capital investment) while their free cash flow is negative. One possible cure for negative free cash flow is higher oil prices. But higher oil prices will lead to increasing energy cost share, and we saw in Sect.1.3.1 that high energy cost share provides recessionary pressure.

citation A:
US Energy Information Agency. 2014. As cash flow flattens, major energy companies increase debt, sell assets. Today In Energy. http://www.eia.gov/todayinenergy/detail.cfm?id=17311. Accessed 22 January 2015.

citation B:

```
@article{Krauss:2014ab,
	Author = {Clifford Krauss},
	Date-Added = {2015-01-08 19:28:13 +0000},
	Date-Modified = {2015-01-08 19:38:57 +0000},
	Journal = {The New York Times},
	Month = {17 October},
	Pages = {B3},
	Title = {Despite Slumping Prices, No End in Sight for {U.S.} Oil Production Boom},
	Year = {2014}}
```

citation C:

@article{Krauss:2015aa,
Author = {Clifford Krauss},
Journal = {The New York Times},
Month = {8 January},
Pages = {B1},
Title = {{U.S.} Oil Producers Cut Rigs as Price Declines},
Year = {2015}}

citation D:
@article{Corkery:2015aa,
Author = {Michael Corkery and Peter Eavis},
Journal = {New York Times},
Month = {12 January},
Pages = {B1},
Title = {As Oil Prices Fall, Banks Serving the Energy Industry Brace for a Jolt},
Year = {2015}}

The justification for the change on p. 15 is that new developments in worldwide oil markets between the time of our submission and now require some commentary.

p. 57:

There is a formatting problem with footnote 9. There is a footnote contained within the footnote. (See “Note that this minimum is likely…”) We propose that footnote 9 be changed as follows:

~~\footnote{As such,~~
~~we can deduce that the economy \emph{must always} be~~
~~a subsidiary of the biosphere, \emph{open} to~~
~~flows of materials both from (resources) and~~
~~to (wastes) the biosphere.~~
~~This fact has direct implications for~~ dematerialization
~~of our economies,~~
~~which was discussed in reference~~
~~to our framework in Section~\ref{sec:recycling}.~~
~~There are fundamental limits to the amount~~
~~of material that must be directed to desired~~
~~end services.~~
~~For example, automobiles~~

must have a minimum level of embodied materials.\footnote{Note
that this minimum is likely many times lower than the
mass of current automobiles,
which are driven largely by preference.
The Rocky Mountain Institute has done some
work on the ultra-light,
``hypercar'' concept.\cite{RMI1996}}
Despite the drive to dematerialization
and the apparent ``unhooking'' of the
material and energy intensity of GDP,
much of the dematerialization of ``developed''
nations has been by exporting manufacturing
to other countries.\cite{allwood2012sustainable}
The material footprint of OECD nations,
when weighted by consumption,
has increased significantly since 1990.\cite{Wiedmann2013}}

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to our framework in Section~\ref{sec:recycling}.
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of material that must be directed to desired
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For example, automobiles
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Note that this minimum is likely many times lower than the
mass of current automobiles,
which are driven largely by preference.
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``hypercar'' concept.\cite{RMI1996}

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material and energy intensity of GDP,
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nations has been by exporting manufacturing
to other countries.\cite{allwood2012sustainable}
The material footprint of OECD nations,
when weighted by consumption,
has increased significantly since 1990.\cite{Wiedmann2013}}

In case it is needed, here is the citation for RMI1996:

```
@article{RMI1996,
  title={Hypercars: Materials, manufacturing, and policy implications},
  author={Lovins, Amory B and Brylawski, Michael M and Cramer, David R and Moore,
Timothy C and others},
  year={1996},
  publisher={Hypercar Center, Rocky Mountain Institute}}
```

Responses to Author Queries:

Chapter 1

AQ1 Author: Please check whether the edits made in the sentence “This predilection results...pursuit of income.” retain your intended sense.

The edits are acceptable. Thank you.

Chapter 2

AQ1 Please provide the publishers’ main locations for the following references:

[1]

```
@book{Box:1987aa,
        Address = {Oxford, England},
        Author = {George E P Box and Norman R Draper},
        Publisher = {Wiley},
        Title = {Empirical Model-Building and Response Surfaces},
        Year = {1987}}
```

[6]
@book{Walras1993,
Address = {London},
Author = {Albert Jolink and Jan Van Daal},
Publisher = {Routledge},
Title = {The Equilibrium Economics of L{\'e}on} Walras},
Year = {1993}}

[9]
@book{Rao2004,
Address = {Hyderabad, India},
Author = {Rao, YVC},
Publisher = {Universities Press},
Title = {An Introduction To Thermodynamics},
Year = {2004}}

[11] <<note publisher has been corrected in the BibTeX entry below.>>
@book{ayres1997,
Address = {New York},
Author = {Ayres, Robert},
Month = aug,
Publisher = {Earthscan},
Title = {Turning Point: End of the Growth Paradigm},
Year = {1997}}

[31]
@book{Georgescu-Roegen:1971aa,
Address = {Cambridge, Massachusetts},
Author = {Nicolas Georgescu-Roegen},
Publisher = {Harvard University Press},
Title = {The Entropy Law and the Economic Process},
Year = {1971}}

[34]
@book{Hall1986,
Address = {New York, N.Y.},
Author = {Hall, Charles A S and Cleveland, Cutler J and Kaufman, Robert},
Publisher = {John Wiley \& Sons},
Title = {Energy and Resource Quality: The Ecology of the Economic Process},
Year = {1986}}

[35]
@book{Heijman:1988aa,
Address = {Dordrecht, Netherlands},
Author = {Wim Heijman},
Publisher = {Kluwer},
Title = {{The Economic Metabolism}},
Year = {1988}}

[40]
@book{Schweid:2004aa,
Address = {Chapel Hill, North Carolina},
Author = {Richard Schweid},
Publisher = {University of North Carolina Press},
Title = {Che's Chevrolet, Fidel's Oldsmobile: On the Road in Cuba},
Year = {2004}}

[44]
@book{kummel2011,
Address = {New York, N.Y.},
Author = {Reiner K\"{u}mmel},
Month = jun,
Publisher = {Springer},
Title = {The Second Law of Economics: Energy, Entropy, and the Origins of Wealth},
Year = {2011}}

AQ2 Please provide the publisher name for the following references:

[33] <<Note several details are changed for this entry.>>
@book{Daly1977,
Address = {Washington, DC},
Author = {Herman E Daly},
Edition = {2nd},
Publisher = {Island Press Washington, DC},
Title = {Steady-State Economics},
Year = {1991}}

[6] <<Same as above.>>
@book{Walras1993,
Address = {London},
Author = {Albert Jolink and Jan Van Daal},
Publisher = {Routledge},
Title = {The Equilibrium Economics of L{\'e}on Walras},
Year = {1993}}

Chapter 3

AQ1 Please provide the significance of “?” in the sentence “is there a flow of resources . . . ”.

The “?” is part of the parenthetical question. Please leave as is.

AQ2 Please provide the publishers’ main locations for the following references:

[7]
@book{Schnaiberg1980,
Address = {Oxford, England},
Author = {Schnaiberg, Allan},
Publisher = {Oxford University Press},
Title = {Environment: from surplus to scarcity},
Year = {1980}}

[10]
@incollection{Daly2006,
Address = {New York, N.Y.},
Author = {Daly, Herman E},
Booktitle = {The future of sustainability},
Pages = {39--53},
Publisher = {Springer},
Title = {Sustainable Development---Definitions, Principles, Policies},
Year = {2006}}

[11]
@book{Giampietro2013,
Address = {London},
Author = {Giampietro, Mario and Mayumi, Kozo and \c{S}orman, Alevg{\"u} H},
Publisher = {Routledge},
Title = {Energy Analysis for a Sustainable Future: Multi-scale Integrated Analysis of Societal and Ecosystem Metabolism},
Year = {2013}}

Chapter 6

AQ1 Please try rephrasing the text “assess the biophysical reality...” for clarity.

Please see annotated .pdf file. Delete “economic reality”.

AQ2 Please provide the publishers’ main locations for the following references:

[3]
@book{Daly1997,
Address = {Boston},
Author = {Daly, Herman E},
Publisher = {Beacon Press},
Title = {Beyond growth: the economics of sustainable development},
Year = {1997}}

[4]
@incollection{Costanza:2004we,
Address = {Amsterdam, Netherlands},

Author = {Costanza, Robert},
Booktitle = {{Encyclopedia of Energy}},
Editor = {Cutler J. Cleveland},
Month = {March},
Pages = {337--346},
Publisher = {Elsevier},
Title = {Value Theory and Energy},
Volume = {6},
Year = {2004}}

Chapter 7

AQ1 Please provide the publishers' main locations for the following references:

[10]
@incollection{Suh2009,
Address = {Netherlands},
Author = {Suh, Sangwon and Huppes, Gjalt},
Booktitle = {Handbook of Input-Output Economics in Industrial Ecology},
Editor = {Suh, Sangwon},
Pages = {263--282},
Publisher = {Springer},
Series = {Eco-Efficiency in Industry and Science},
Title = {Methods in the Life Cycle Inventory of a Product},
Volume = {23},
Year = {2009}}

[19]
@book{Hendrickson2006,
Address = {Washington, DC},
Author = {Hendrickson, Chris T and Lave, Lester B and Matthews, H Scott},
Publisher = {Resources for the Future},
Title = {Environmental life cycle assessment of goods and services: an input-output approach},
Year = {2006}}

[22]
@book{Beyer:1991vd,
Address = {Boca Raton, Florida},
Author = {Beyer, William H},
Edition = {29$^{\mathrm{th}}$},
Publisher = {CRC Press},
Title = {Standard Mathematical Tables and Formulae},
Year = {1991}}

Chapter 8

AQ1 We have changed the word “ambodied” to “embodied” in the abstract. please check and confirm.

This change is acceptable.

AQ2 We have inserted the full form of the abbreviation “BEA”. Please check and confirm.

This change is acceptable.

AQ3 Please provide access dates for the following references:
[1]
Accessed 22 January 2015.

[14]
Accessed 22 January 2015.

[17]
Accessed 22 January 2015.

[19]
Accessed 22 January 2015.

AQ4 Please provide the publishers’ main locations for the following references:
[8]
@book{Meadows2008,
Address = {White River Junction, Vermont},
Author = {Meadows, Donella H},
Publisher = {Chelsea Green Publishing},
Title = {Thinking in systems: A primer},
Year = {2008}}

[9]
@book{allwood2012sustainable,
Address = {Cambridge, England},
Author = {Julian M Allwood and Jonathan M Cullen and Mark A Carruth and Daniel R Cooper and Martin McBrien and Rachel L Milford and Muiris C Moynihan and Alexandra CH Patel},
Publisher = {UIT Cambridge Limited},
Title = {Sustainable Materials: with both eyes open},
Year = {2012}}

[27]
@book{Bostrom2011,

Address = {Oxford, England},
Author = {Bostrom, Nick and Cirkovic, Milan M},
Publisher = {Oxford University Press},
Title = {Global catastrophic risks},
Year = {2011}}

[31]
@book{Daly1997,
Address = {Boston},
Author = {Daly, Herman E},
Publisher = {Beacon Press},
Title = {Beyond growth: the economics of sustainable development},
Year = {1997}}

[34]
@book{Wackernagel1996,
Address = {Gabriola Island, British Columbia, Canada},
Author = {Mathis Wackernagel},
Publisher = {New Society Publishers},
Title = {Our ecological footprint: reducing human impact on the earth},
Volume = {9},
Year = {1996}}

AQ5 Please provide the complete details for the following references
[20]
@article{Lawn:2003aa,
Author = {Philip A Lawn},
Journal = {Ecological Economics},
Pages = {105-118},
Title = {A Theoretical Foundation to Support the Index of Sustainable Economic Welfare ({ISEW}), Genuine Progress Indicator ({GPI}), and Other Related Indexes},
Volume = {44},
Year = {2003}}

[28]
@misc{Eclipsenow2014,
Author = {Neil Cameron},
Howpublished = {http://eclipsenow.wordpress.com/doomers},
Title = {{Peakniks, Doomers and Collapse}},
Year = {2010}}
Accessed 9 December 2014

[36]
@incollection{Daly2006,
Address = {New York, N.Y.},
Author = {Daly, Herman E},
Booktitle = {The future of sustainability},
Pages = {39--53},
Publisher = {Springer},
Title = {Sustainable Development---Definitions, Principles, Policies},
Year = {2006}}

AQ6 Please provide the publisher name for reference:
[32] <<Note several details have changed on this reference.>>
@book{Daly1977,
Address = {Washington, DC},
Author = {Herman E Daly},
Edition = {2nd},
Publisher = {Island Press Washington, DC},
Title = {Steady-State Economics},
Year = {1991}}

Chapter Abstracts:

The *Revised Abstracts.txt* file that was sent with the submitted manuscript was not incorporated into the proof sent to the authors. The abstracts included in the author proofs is incorrect and must be replaced with the text below.

Chapter 1:

We are entering a new era in which
biophysical limits related to natural resource extraction rates and
the biosphere's waste assimilation capacity
are becoming binding constraints on mature economies.
Unfortunately, the data needed for policy-makers to understand and manage
economic growth in the new era are not universally available.
In this chapter, we discuss the problems that arise from relying solely
on the Solow growth model to describe an economy that is,
in reality, deeply interconnected with the biosphere.
We point out that mainstream economists forecast low growth rates
for mature economies for the foreseeable future,
because traditional drivers of economic growth
(growth rates of capital and labor productivity) have plateaued.
Unfortunately, mainstream policy recommendations to reinvigorate growth,

based on the Solow growth model,
ignore three critical realities:
the economy is tightly coupled to the biosphere,
there exist real and binding physical and technological limits
to the rate at which materials and energy can be extracted from the biosphere, and
today's emplacement of manufactured capital locks in tomorrow's
material and energy demands from the biosphere.
As such, mainstream policy recommendations are likely to fail in the long run:
today's expansion of the stock of capital in the economy
in the hopes of enhancing consumption can contribute to the
slowdown of economic growth by bringing us ever-closer to biophysical limits.
The chapter ends by noting that we need a new way to understand our economy,
and we suggest that
detailed information about materials, energy, embodied energy, and energy intensity
be routinely gathered and analyzed and disseminated from a centralized location
to provide markets and policymakers with more-complete knowledge
of the biophysical economy.
However, a firm theoretical underpinning is needed before proceeding
along this new path,
and the remainder of this book provides a rigorous theoretical framework
for a better system of national accounts, one that goes beyond GDP
and one that is relevant to the age of resource depletion.

Chapter 2:

Mainstream economic models,
which typically exclude physical transactions
between the economy and the biosphere,
are incomplete:
wastes, pollution, natural resource extraction, and
use of ecosystem services are not included.
When economic policy is informed by these incomplete models,
unexpected negative outcomes can arise.
In this chapter, we suggest
that the reason for the incompleteness of mainstream economic models is
that we incorrectly understand the economy
through the outdated metaphor of the economy as a machine.
We describe three eras of thinking about the economy,
its relationship to the biosphere, and the
metaphors that emerged during each era.
We argue that as the world enters the age
of resource depletion, it is time for a new metaphor:
the economy is society's \emph{metabolism}.
We describe the metabolic processes
of anabolism, catabolism, and autophagy

and draw analogies
to key economic processes:
capital formation, energy production, and recycling.
Based on the machine metaphor, today's economic policies are unable
to address important issues such as appropriate levels and types of capital formation,
efficient energy production, wise use of recycling, and
the appropriate scale of the economy relative to the biosphere.
The problem is compounded by today's national accounting,
which fails to count many beneficial activities in GDP,
simply because because GDP measures only what is produced.
Thus, wise and beneficial long-term decisions that would that preserve or enhance
natural capital (such as refraining from clearcutting forests)
might, ultimately, reduce GDP.
We conclude that navigating through the age of resource depletion
will require expanded national accounting that captures
robust, annual data on the entire portfolio of a nation's wealth
(manufactured and natural capital) in addition to
data on national income (GDP).
The chapter ends with a description of the structure of the rest of the book.

Chapter 3:

The first step in understanding the economic metabolism
is to account for the flow of materials through the economy
and the exchange of materials with the biosphere.
In this chapter, we develop a framework
for accounting material flows and accumulation
within economies.
We begin by considering accounting in everyday life
and continue with concepts from thermodynamics,
such as system boundaries, control volumes, and
the First Law of Thermodynamics,
to develop a rigorous accounting framework.
The framework is applied first to a one-sector then
two-sector model of the economy
as we construct a general framework for material
accounting.
We then apply the framework to the real-world
example of the US auto industry.

Chapter 4:

Accounting for direct energy as it flows through an economy is essential
for developing a dynamic picture of its metabolism.
In this chapter, we apply the First Law of Thermodynamics
to sectors of the economy to describe flows of direct energy
from the biosphere, through economies, and ultimately back to the biosphere as waste heat.
Direct energy accounting equations are developed through a series
of example economies with increasing levels of disaggregation.
Finally, direct energy flows for the example of the US auto industry are discussed.

Chapter 5:

In addition to materials and direct energy,
accounting for embodied energy is essential to understand
how the biophysical economy operates, because it provides an indication of the
distribution of intra-economy energy demand created by consumption of goods and services.
Furthermore, the energy embodied in manufactured capital
provides, to first approximation, an estimate of the energy required to replace
depreciated capital.
This chapter begins by developing, for the first time in the literature,
a rigorous, thermodynamically-based definition of embodied energy.
We then show that energy embodied in the products of an economic sector
is the sum of all direct energy
consumed along the supply chain,
including all upstream processing stages.
We note that waste heat from a sector is additive to the energy
embodied within products of a sector,
thereby providing the mechanism for accumulating
embodied energy along the manufacturing supply chain.
Equations that describe
the accumulation and flow of embodied energy through economies are developed
through a series of increasingly-disaggregated model economies.
Finally, we discuss embodied energy in the context of our running example,
the US auto industry.
We find that there are very few estimates in the literature
of energy embodied within automobiles.

Chapter 6:

To quantify financial activities and interdependencies within an economy,
economists account for flows of economic value among sectors of the economy.
In this chapter, we utilize the prevailing subjective theory of value
to develop a framework for value accounting that is consistent with the

materials, energy, and embodied energy accounting frameworks
presented in prior chapters.
We note that important and essential material exchanges between the economy and the biosphere
(including energy extraction from the biosphere and waste assimilation by the biosphere)
take place outside of the market, and, as such, they are not included in
national accounts and have no economic value.
We point to the UN System of Environmental Economic Accounts (SEEA)
or the US Integrated Environmental Economic Satellite Accounts (IEESA) as the way forward
to including some of these essential extra-market transactions in national accounting.
Similar to previous chapters,
a series of increasingly-disaggregated model economies is used
to develop our value accounting framework.
Value flows for the US auto industry are presented,
and concerns are raised about recent changes to include intangible assets,
such as software and intellectual property, as capital stock.

Chapter 7:

Energy intensity,
the ratio of total energy consumed during the manufacture of a product
to the economic value of that product expressed in units of J/\$,
is an inherently useful metric that describes the accumulation
of energy consumption and economic value along
the pathways traveled by products through an economy.
It is a key piece of information that can help consumers and firms alike
make wise consumption and investment decisions in the age of resource depletion.
The Energy Input-Output (EI-O) method, developed by
Bullard, Herendeen, and others as an extension to Leontief's groundbreaking work,
has been used historically to develop
static estimates of the energy intensity of products within economy.
Unfortunately, energy intensity is not routinely estimated, and, if it is,
it erroneously does not account for the energy embodied
in our accumulating stock of manufactured capital.
In this chapter, we extend the EI-O method
to develop a mathematical technique to estimate
energy intensity in a dynamic economy,
one that can accumulate manufactured capital in its sectors.
As in previous chapters,
the equations are developed by example in increasingly-disaggregated model economies.
We review several studies of energy intensity of the US auto industry in the literature
and note a wide range of results from one study to the next.
The estimates of energy intensity also vary with time.
The range of energy intensities for the auto sector
is 0.83×10^{4} kJ/\$ to 11.6×10^{4} kJ/\$.

Chapter 8:

The metabolism metaphor and the material, energy, and economic value accounting framework presented in the book have a number of implications for the manner in which we understand our economies. In this chapter, we discuss several of these implications. The first set of implications is for the Energy Input-Output method itself. We recommend a physical accounting framework that fully accounts for capital stock and energy input from society (final consumption) to the economy. We then discuss implications for economic ``development,'' namely that economic growth could be considered a ``fully coupled'' problem: understanding it requires breadth of knowledge and appreciation for interactions among many important and complementary factors, including financial capital, manufactured capital and associated embodied energy, natural capital, direct energy, and societal inputs. Each, alone, is necessary, but not sufficient, for economic development. We discuss implications for recycling and reuse of materials and for the concept of dematerialization. Finally, we view the concept of a steady-state economy through the lens of our framework. We find that there are many potential definitions of a steady-state economy, none of which are fully satisfying when compared against the ideal of sustainability.

Chapter 9:

The dynamic accounting framework presented in previous chapters naturally gives rise to a set of next steps necessary to expand systems of national accounts to encompass material and energy flows within our economies and exchanges with the biosphere. This final chapter briefly summarizes the book and highlights the need for additional data on both inter-sector flows and accumulation of manufactured capital and its embodied energy. We continue with a call to action, a list of several tasks that should be undertaken to modify national accounting. Finally, we note that moving forward on these issues will be politically difficult, but necessary, to adapt to the age of resource depletion.