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**Sustainability and the Global Biogeochemical Cycles:  
Integrated modelling of coupled economic and  
environmental systems**

A thesis presented in partial fulfilment of the requirements for the degree of

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In

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## Abstract

The global biogeochemical cycles (GBCs), which include cycles of C, N, P, S, Cl, I, and H<sub>2</sub>O, are extremely important biosphere functions, critical to the maintenance of conditions necessary for all life. Importantly, perturbation of these GBCs has the potential to affect the structure and functioning of the Earth system as a whole. While biogeochemistry research to date has largely focused on 'natural' processes, human economic activities are increasingly recognised as integral components of the GBCs. This thesis draws on both static and dynamic-system modelling approaches to describe the coupled economic and GBC systems, and to develop tools to assist in learning about these systems, with the aim of progressing towards sustainability. First, by drawing on the theoretical frameworks of Input-Output Analysis and Material Flow Analysis, an extensive and coherent static system model of the global C, N, P and S cycles is presented. Data within that static model are then used to calculate a set of sustainability indicators, based on a new and novel concept of 'ecotime'. Essentially, these indicators describe the level at which the global economy, through its transformation of useful resources (i.e. raw materials) into residuals (i.e. wastes, pollutants, emission), appropriates biogeochemical processes. Changes in these and other indicators, under possible future scenarios, are also able to be investigated by a new dynamic model known as 'Ecocycle'. Ecocycle constitutes one of very few attempts to develop an integrated model of the Earth system, explicitly capturing relationships between the GBCs and human activities. A notable feature of Ecocycle is that it represents the general equilibrium-seeking behaviour of an economy within a System Dynamics modelling approach, rather than through an optimisation approach as typically employed. A further significant methodological contribution of the thesis is the development of a technique for translating IO-based accounts between alternative process-by-commodity, commodity-by-commodity, and process-by-process frameworks. This method is required for both the static and dynamic components of the thesis.



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## List of Abbreviations

### Acronyms

Acronym	Name
AR4	IPCC Fourth Assessment Report
BOD	Biological Oxygen Demand
CES	Constant Elasticity of Substitution
CET	Constant Elasticity of Transformation
CGE	Computable General Equilibrium
COD	Chemical Oxygen Demand
CTA	Commodity Technology Assumption
DGBCM	Dynamic Global Biogeochemical Cycling Model
DGES	Dynamic General Equilibrium Seeking
DIC	Dissolved Inorganic Carbon
DOC	Degradable Organic Carbon
EDGAR	Emission Database for Global Atmospheric Research
EF	Ecological Footprint
ESAM	Environmentally-Extended Social Accounting Matrix
FAO	Food and Agricultural Organisation
FCS	Fixed Commodity Sales Structure
FIS	Fixed Industry Sales Structure
GHG	Greenhouse Gases
GTAP	Global Trade Analysis Project
GUMBO	Global Unified Metamodel of the Biosphere
IMAGE	Integrated Modelling of Global Environmental Change
IO	Input-Output
IPCC	Intergovernmental Panel on Climate Change
ISW	Industrial Solid Waste
ITA	Industry Technology Assumption
MA	Millenium Ecosystem Assessment
MFA	Materials Flow Analysis
NPP	Net Primary Production
PIOT	Physical Input-Output Table
SAM	Social Accounting Matrix
SIOT	Symmetric Input-Output Table
SUT	Supply-Use Table
TAR	IPCC Third Assessment Report
VOCs	Volatile Organic Compounds

### SI Units

Symbols	Prefixes	Multiples
Z	Zetta	1 000 000 000 000 000 000 = $10^{21}$
E	Exa	1 000 000 000 000 000 000 = $10^{18}$
P	Peta	1 000 000 000 000 000 = $10^{15}$
T	Tera	1 000 000 000 000 = $10^{12}$
G	Giga	1 000 000 000 = $10^9$
M	Mega	1 000 000 = $10^6$
k	kilo	1 000 = $10^3$

### Chemical Formula

Formula	Name
C	Carbon
CaCO <sub>3</sub>	Calcium carbonate
CH <sub>4</sub>	Methane
CO	Carbon monoxide
CO <sub>2</sub>	Carbon dioxide
CS <sub>2</sub>	Carbon disulphide
DMS	Dimethyl sulphide (CH <sub>3</sub> ) <sub>2</sub> S
H <sub>2</sub> CO <sub>3</sub>	Carbonic acid
H <sub>2</sub> S	Hydrogen disulphide
HCO <sub>3</sub> <sup>-</sup>	Bicarbonate
HNO <sub>3</sub>	Nitric acid
N	Nitrogen
N <sub>2</sub>	Dinitrogen
N <sub>2</sub> O	Nitrous oxide
NH <sub>3</sub>	Ammonia
NH <sub>4</sub> <sup>+</sup>	Ammonium
NO	Nitric oxide
NO <sub>2</sub>	Nitrogen dioxide
NO <sub>3</sub> <sup>-</sup>	Nitrate
OCS	Carbonyl sulphide
P	Phosphorus
PO <sub>4</sub> <sup>3-</sup>	Phosphate
S	Sulphur
SO <sub>2</sub>	Sulphur dioxide
SO <sub>4</sub> <sup>2-</sup>	Sulphate

