Table of contents

1 Introduction and aim ................................................................. 1
  1.1 Motivation: Biorefineries as partial solution to global challenges?  1
  1.2 Aim of the work ............................................................... 3
  1.3 Outline of the work .......................................................... 5

2 Concepts, rules, and strategies to operationalise sustainability .... 7
  2.1 Genesis of the paradigm of sustainable development .............. 7
  2.2 Rules and strategies of resources and environmental management ...
      2.2.1 Efficiency ................................................................. 10
      2.2.2 Sufficiency .............................................................. 12
      2.2.3 Consistency ............................................................. 12
  2.3 Dealing with natural capital: strong and weak sustainability .... 13
  2.4 Sustainability concepts ..................................................... 16
      2.4.1 Three-pillar concept .................................................. 17
      2.4.2 Integrative sustainability concepts ................................ 17
  2.5 Selection of a sustainability concept to assess bio-based products ... 21
  2.6 A closer look at the selected integrative concept of
      sustainable development ..................................................... 25

3 Biorefinery concepts ............................................................... 30
  3.1 Biorefinery definition .......................................................... 30
  3.2 Classification method for biorefinery systems ........................... 32
      3.2.1 Raw materials for biorefineries .................................... 33
      3.2.2 Platforms of biorefineries .......................................... 34
      3.2.3 Technologies and processes of biorefineries ................. 35
      3.2.4 Markets and products .............................................. 36
  3.3 Technological concepts ....................................................... 39
      3.3.1 Overview of biorefinery concepts ................................. 39
      3.3.2 Algae biorefineries .................................................... 41
  3.4 Contribution of biorefineries to resource conservation ........... 45
  3.5 Challenges for the successful implementation of biorefineries .... 46
      3.5.1 General requirements for the successful implementation of
      biorefineries ....................................................................... 46
      3.5.2 Ways towards the realisation of algae biorefineries .......... 47
4 Design of a generic methodology to assess the sustainability impact of biorefineries

4.1 Definition of generic sustainability criteria of biorefineries

4.1.1 Identification and definition of biorefinery specific sustainability criteria using substantial rules

4.1.2 Comparison of sustainability criteria for biorefineries and biomass production with literature

4.1.3 Sustainability criteria requested by legal requirements

4.1.4 Summary and cluster of sustainability criteria of biorefineries

4.2 Definition of generic sustainability indicators for biorefineries

4.2.1 Requirements of indicators

4.2.2 Indicators addressed by life cycle assessment approaches

4.2.3 Complementary sustainability indicators

4.3 Instruments to evaluate sustainability impacts of biorefineries

4.3.1 Life cycle assessment

4.3.2 Complementary instruments and information to evaluate additional sustainability effects

4.4 Dealing with conflict of aims

5 Specification, application, and validation of the generic methodology for an algae biorefinery in the context of bio-based economy

5.1 Objective of the case study

5.2 Classification of the algae biorefinery

5.3 Specification of sustainability criteria and indicators for an algae biorefinery

5.3.1 Health impacts and risks

5.3.2 Environmental impacts

5.3.3 Impacts on knowledge and physical capital

5.3.4 Impacts on regional development and acceptance

5.4 Life cycle analysis: goal and scope

5.4.1 Goal definition

5.4.2 Scope definition

5.4.3 Products and reference system

5.4.4 Functional unit

5.4.5 System boundaries

5.4.6 Cut-off criteria

5.4.7 Solving multifunctionality of processes

5.4.8 Uncertainty, sensitivity, and scenario analyses