



**Universiteit
Leiden**
The Netherlands

Software and data for circular economy assessment

Donati, F.

Citation

Donati, F. (2023, April 26). *Software and data for circular economy assessment*. Retrieved from <https://hdl.handle.net/1887/3594655>

Version: Publisher's Version

License: [Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/3594655>

Note: To cite this publication please use the final published version (if applicable).

Software and Data for Circular Economy Assessment

Franco Donati

© **Franco Donati (2023)**

Software and Data for Circular Economy Assessment

ISBN/EAN: 9789051912043

Cover design and layout: Franco Donati

Art design made with Python Samila and exiobase 3.8 IOT pxp 2017

Software and Data for Circular Economy Assessment

Proefschrift

ter verkrijging van
de graad van doctor aan de Universiteit Leiden,
op gezag van rector magnificus prof.dr.ir. H. Bijl,
volgens besluit van het college voor promoties
te verdedigen op woensdag 26 april 2023
klokke 11:15 uur

door

Franco Donati

geboren te Sassari, Italië

in 1987

Promotor: Prof. dr. A. Tukker

Promotiecommissie: Prof. dr. H. Lin
Prof. dr. ing. J.W. Erisman
Prof. Dr. K. Hubacek (Rijksuniversiteit Groningen)
Dr. R. Wang
Dr. O. Ivanova (Planbureau voor de Leefomgeving)

TABLE OF CONTENTS

| | | |
|----------|--|-----------|
| 1 | Introduction | 1 |
| 1.1 | Circular economy | 1 |
| 1.2 | Models for circular economy assessment | 5 |
| 1.3 | Software and data for Circular Economy assessment | 11 |
| 1.4 | Problem statement and research questions | 13 |
| 1.5 | Structure of the thesis | 14 |
| | | |
| 2 | Environmental Pressures and Value Added Related to Imports and Exports of the Dutch Agricultural Sector | 21 |
| 2.1 | Introduction | 22 |
| 2.2 | Materials and Methods | 23 |
| 2.2.1 | General Methods and Data | 23 |
| 2.2.2 | Data | 24 |
| 2.2.3 | Contribution Analysis | 25 |
| 2.3 | Results | 25 |
| 2.3.1 | Greenhouse Gas Emissions | 26 |
| 2.3.2 | Land Use | 29 |
| 2.3.3 | Water Consumption | 31 |
| 2.4 | Discussion | 34 |
| 2.5 | Conclusions | 35 |
| | | |
| 3 | Modeling the circular economy in environmentally extended input-output tables: Methods, software and case study | 43 |
| 3.1 | Introduction | 44 |
| 3.2 | Methods | 47 |
| 3.2.1 | CE policy modelling framework | 47 |
| 3.2.2 | Environmentally Extended Input-Output (EEIO) analysis | 48 |
| 3.2.3 | Baseline and counterfactual scenario | 49 |

| | | |
|----------|--|-----------|
| 3.2.4 | Change coefficients and substitution | 50 |
| 3.2.5 | Modeling CE interventions in EEIO | 51 |
| 3.3 | Data, software and case study settings | 55 |
| 3.3.1 | Data | 55 |
| 3.3.2 | Software | 55 |
| 3.3.3 | Case study settings | 56 |
| 3.4 | Results | 60 |
| 3.4.1 | Impact of the strategies | 60 |
| 3.4.2 | Impact of individual interventions | 63 |
| 3.5 | Discussion | 66 |
| 3.5.1 | Methods and framework | 66 |
| 3.5.2 | Software and Data | 67 |
| 3.5.3 | Case study | 67 |
| 3.5.4 | Future work | 69 |
| 3.6 | Conclusions | 69 |
| 4 | Modeling the Circular Economy in Environmentally Extended Input-Output: A web-application | 77 |
| 4.1 | Introduction | 78 |
| 4.2 | Requirements, review of existing software, and design choices for Rama Scene | 79 |
| 4.2.1 | Review of existing software | 79 |
| 4.2.2 | Implications and design choices for the RaMa-Scene platform | 82 |
| 4.3 | Data, Methods and User Interface | 83 |
| 4.3.1 | Data | 83 |
| 4.3.2 | Methods | 84 |
| 4.3.3 | Baseline and Counterfactual scenarios | 89 |
| 4.3.4 | The Rama-Scene user interface | 91 |
| 4.4 | Use cases | 93 |
| 4.4.1 | Which country is responsible for the highest amount of material extraction due to their consumption? | 93 |

| | | |
|----------|--|------------|
| 4.4.2 | Which sub-sectors are the top CO ₂ -eq emitters in Italy? | 95 |
| 4.4.3 | What global effects does the increase in secondary steel content in “Electrical machinery and apparatus n.e.c.” (EMA) have on total Greenhouse Gas Emissions (GHGs)? | 96 |
| 4.5 | Discussion and conclusions | 99 |
| 5 | LCI data from Computer-Aided Technologies and Artificial Intelligence: a systematic review | 107 |
| 5.1 | Introduction | 108 |
| 5.2 | Background | 109 |
| 5.2.1 | Life Cycle Inventories (LCIs) | 110 |
| 5.2.2 | Computer-Aided Technologies (CAx) | 111 |
| 5.2.3 | Artificial intelligence (AI) | 112 |
| 5.3 | Approach to the literature review | 113 |
| 5.4 | Results | 114 |
| 5.4.1 | Overview of literature findings | 114 |
| 5.4.2 | How CAx can be used to estimate data for LCIs | 119 |
| 5.4.3 | How AI methods can be used to estimate data for LCIs | 125 |
| 5.4.4 | Integration: how the combination of CAx and AI methods can be used to obtain data for LCIs | 129 |
| 5.5 | Discussions and conclusions | 131 |
| 6 | The future of artificial intelligence in the context of industrial ecology | 147 |
| 6.1 | Introduction | 148 |
| 6.2 | Envisioning the role of AI in IE | 150 |
| 6.3 | Challenges | 153 |
| 6.3.1 | Resource requirements | 153 |
| 6.3.2 | Data accessibility and governance | 154 |
| 6.3.3 | Explainability, interpretability and causality | 156 |
| 6.4 | Recommendations | 156 |

| | | |
|----------|---|------------|
| 7 | Discussions and Conclusions | 165 |
| 7.1 | Introduction | 165 |
| 7.2 | Conclusions | 166 |
| 7.2.1 | Introduction | 166 |
| 7.2.2 | How can MR EEIO be used for priority setting for CE interventions? | 166 |
| 7.2.3 | How can CE strategies be modelled in MR EEIO? | 167 |
| 7.2.4 | How can we create a user-friendly interface for modelling CE strategies with MR EEIO, easily accessible for non-specialists? | 168 |
| 7.2.5 | How can we use Computer-Aided Technologies (CAx) and Artificial Intelligence (AI) methods to increase data availability for the analysis of CE? | 169 |
| 7.2.6 | How can the IE community position itself with regards to AI and digital technologies to better support sustainability and CE assessment? | 170 |
| 7.2.7 | Answer to the main research question | 171 |
| 7.3 | Limitations and suggestions for further research | 172 |
| 7.4 | Implications and reflections | 176 |
| | Summary | 183 |
| | Samenvatting | 189 |
| | Curriculum vitae | 195 |
| | List of publications | 196 |
| | Acknowledgements | 197 |