MODELLING ECONOMY-WIDE MATERIAL STOCKS

OF BUILDINGS, INFRASTRUCTURE AND MACHINERY,

FOR MULTIPLE MATERIAL CYCLES

AND END-USES AROUND THE WORLD

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Motivation: Understanding the Role of Material Stock Patterns for the Transformation to a Sustainable Society (MAT_STOCKS)

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- Material stocks of buildings, infrastructure and machinery are the physical basis of production and consumption and lock-in material and energy flows for construction, operation and via end-of-life waste
  (Pauliuk & Hertwich 2015; Lanau et al. 2019).
- Material stocks and flows of energy and materials provide material & energy services and wellbeing
  (Haberl, Wiedenhofer, et al. 2017; Kalt, Wiedenhofer, et al. 2019; Carmona et al.)
- Develop stock-flow-service consistent insights for a sustainability transformation
  (Haberl, Wiedenhofer, et al., 2017; 2019)
- Existing research focused on specific stock-flow-service relations, e.g. living space, mobility, ….
  (e.g. Pauliuk et al. 2021; Virag et al. 2021)
- … or too aggregate / not linking to services (e.g. MISO-1 in Wiedenhofer et al. 2021; Krausmann et al. 2017; Streeck et al. 2021)

Project homepage: **matstocks.boku.ac.at**

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Starting point: the dynamic stock-flow model tracing Material Inputs, Stocks and Outputs (MISO version 1)

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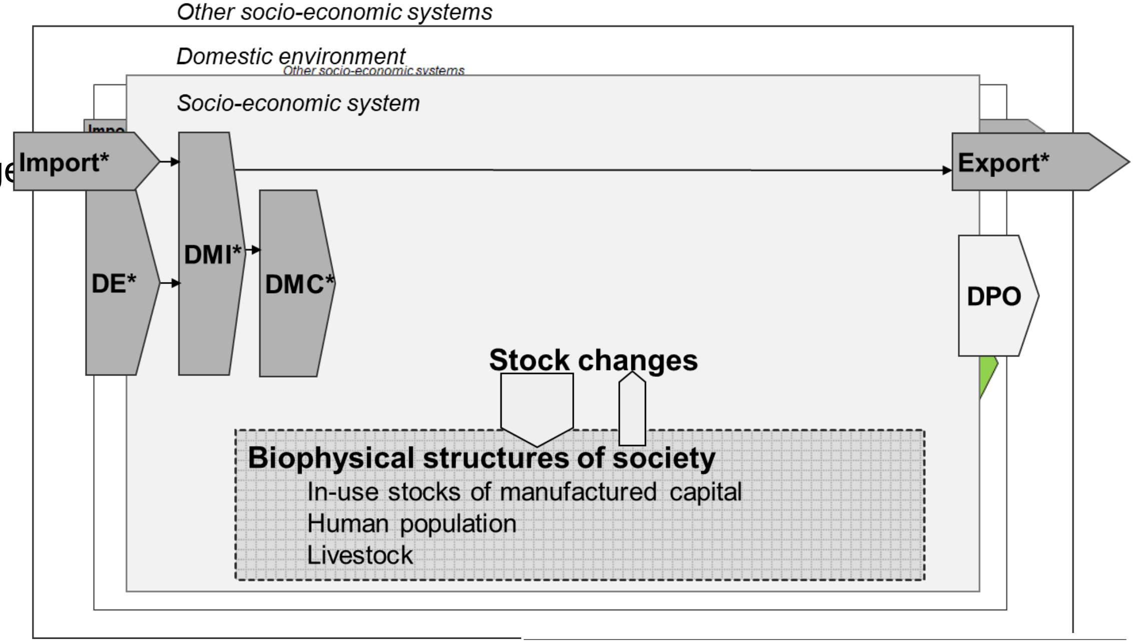
MISO-1 is an extension to economy-wide material flow accounting (Wiedenhofer et al. 2019)

- Combines **accounting in excel** with an implementation in **MatLab**
- Simple input data uncertainty assessment using literature and own knowledge
- Monte-Carlo Simulations & first order Global Sensitivity Analysis

-> Lacks process- and end-use differentiations

-> Inflexible regarding non-normal distributions for lifetimes & uncertainty

-> handling of data inputs & model outputs not standardized



Global socioeconomic material stocks rise 23-fold over the 20th century and require half of annual resource use

Fridolin Krausmann[a,1], Dominik Wiedenhofer[a], Christian Lauk[a], Willi Haas[a], Hiroki Tanikawa[b], Tomer Fishman[b,c], Alessio Miatto[b], Heinz Schandl[d], and Helmut Haberl[a]

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PNAS

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RESEARCH AND ANALYSIS

JOURNAL OF INDUSTRIAL ECOLOGY WILEY

The role of socio-economic material stocks for natural resource use in the United States of America from 1870 to 2100

Jan Streeck | Quirin Dammerer | Dominik Wiedenhofer | Fridolin Krausmann

Ecological Economics 156 (2019) 121–133

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Methodological and Ideological Options

Integrating Material Stock Dynamics Into Economy-Wide Material Flow Accounting: Concepts, Modelling, and Global Application for 1900–2050

Dominik Wiedenhofer[a,*], Tomer Fishman[b], Christian Lauk[a], Willi Haas[a], Fridolin Krausmann[a]

Resources, Conservation & Recycling 163 (2020) 105076

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Spaceship earth's odyssey to a circular economy - a century long perspective

Willi Haas[*], Fridolin Krausmann, Dominik Wiedenhofer, Christian Lauk, Andreas Mayer

Global Environmental Change 71 (2021) 102410

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

Prospects for a saturation of humanity's resource use? An analysis of material stocks and flows in nine world regions from 1900 to 2035

Dominik Wiedenhofer[a,*], Tomer Fishman[b], Barbara Plank[a], Alessio Miatto[c], Christian Lauk[a], Willi Haas[a], Helmut Haberl[a], Fridolin Krausmann[a]

Aims for MISO-2

Address economy-wide stock-flow-service relations

- for all countries, long time periods and all “major/bulk” materials
- Differentiation of end-uses
- Model data inputs on country-level, consistent globally
- Systematic uncertainty assessment

Developments for MISO-2:

- switch code and model structure from MatLab in MISO-1, to python & ODYM (Pauliuk and Heeren, 2020)
- GitHub as team
- Combine WIO and dynamic MFA to improve end-use differentiation for MISO-2 (Streeck et al., in revision)
- Operationalize and apply uncertainty quantification framework (Laner et al, 2014; Plank et al. 2022)
- Implement Monte-Carlo Simulations with ODYM *(thanks to Christoph Hellbig for sharing his MCS code!)*

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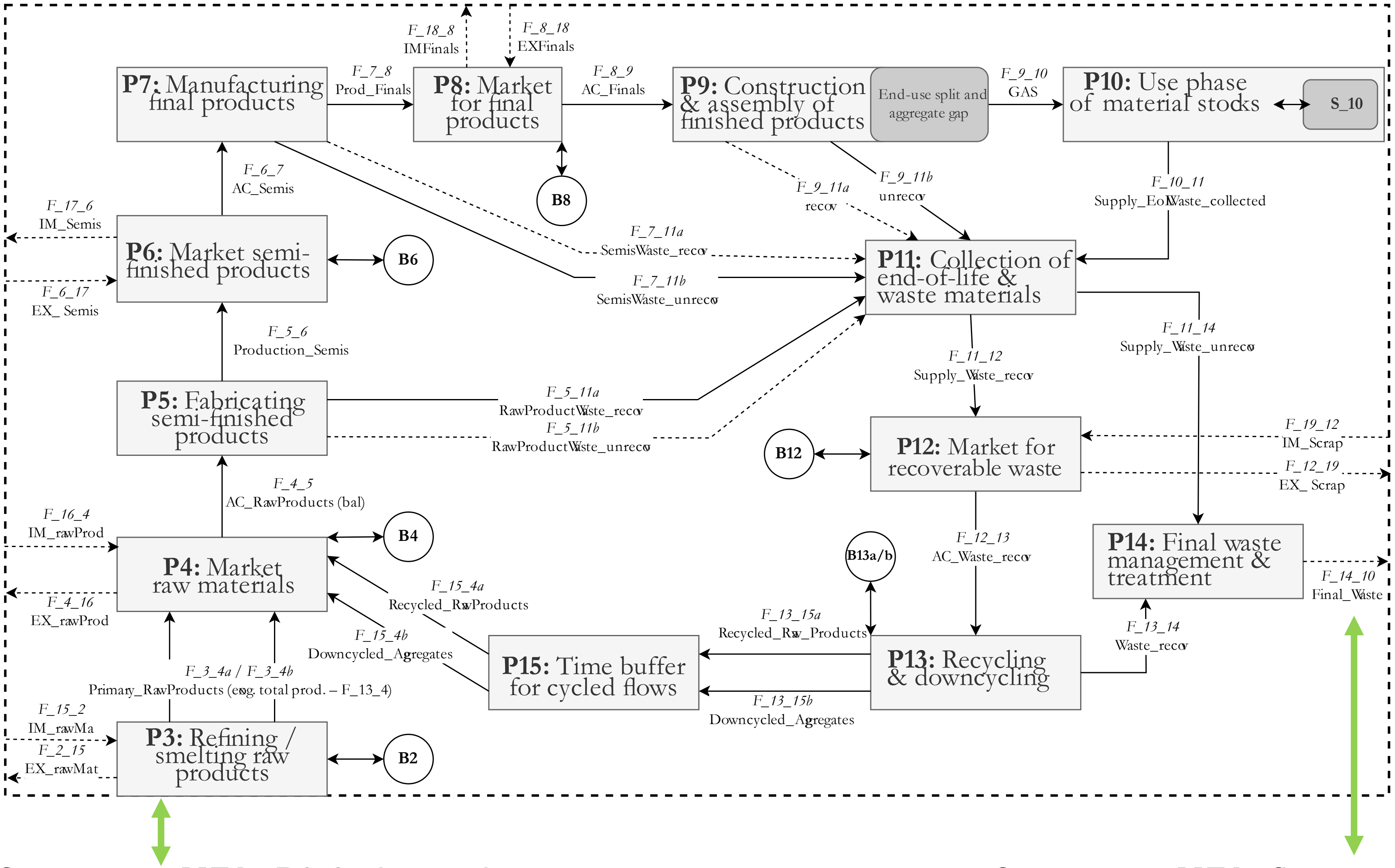
System Definition for ODYM-MISO-2



Interface to ew-MFA: P0-2: the environment, domestic extraction (DE) and primary processing. (Plank et al. 2022). https://doi.org/10.1016/j.resconrec.2021.106122

Interface to ew-MFA: final waste links to indicator Domestic Processed Outputs (DPO)

Scope:

- National to global
- 15 processes
- ~20 materials
- Multiple trade flows
- Balancing items for mismatches between production & trade data
- Multiple recoverable & unrecoverable waste flows
- Recycling & downcycling

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Developing global, country-level model input data for MISO-2

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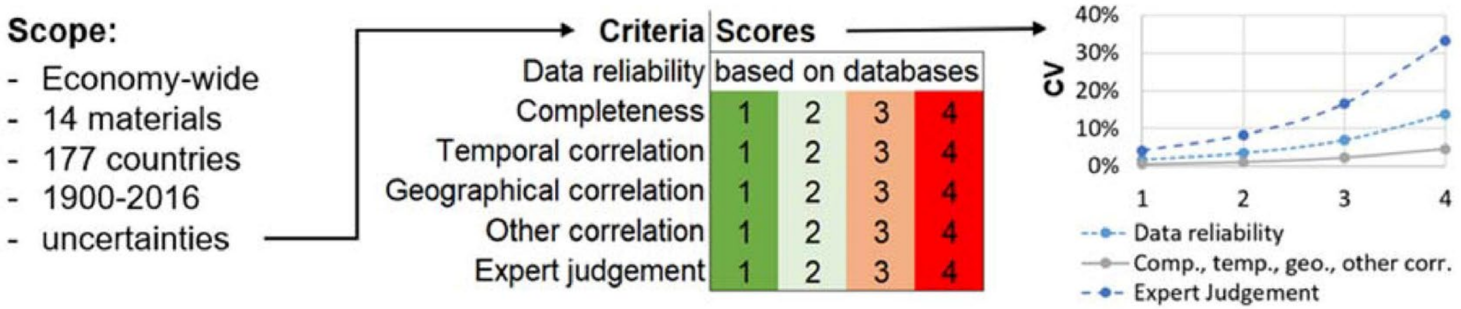
Key innovations:

- Combination of *economy-wide* material flow *accounting* system boundaries and material flow *analysis* principles to differentiate processes, markets and multiple flows, while remaining consistent with ew-MFA
- Systematic 10-step data compilation & harmonization, incl. standardized interpolations & country-disaggregations (e.g. UDSSR)
- Systematic data uncertainty assessment for all model input data, operationalizing Laner et al. (2014; 2015)



Contents lists available at ScienceDirect
Resources, Conservation & Recycling
journal homepage: www.elsevier.com/locate/resconrec

From resource extraction to manufacturing and construction: flows of stock-building materials in 177 countries from 1900 to 2016

Barbara Plank*, Jan Streeck, Doris Virág, Fridolin Krausmann, Helmut Haberl, Dominik Wiedenhofer

Contents lists available at ScienceDirect
MethodsX
journal homepage: www.elsevier.com/locate/mex

Method Article

Compilation of an economy-wide material flow database for 14 stock-building materials in 177 countries from 1900 to 2016☆

Barbara Plank*, Jan Streeck, Doris Virág, Fridolin Krausmann, Helmut Haberl, Dominik Wiedenhofer

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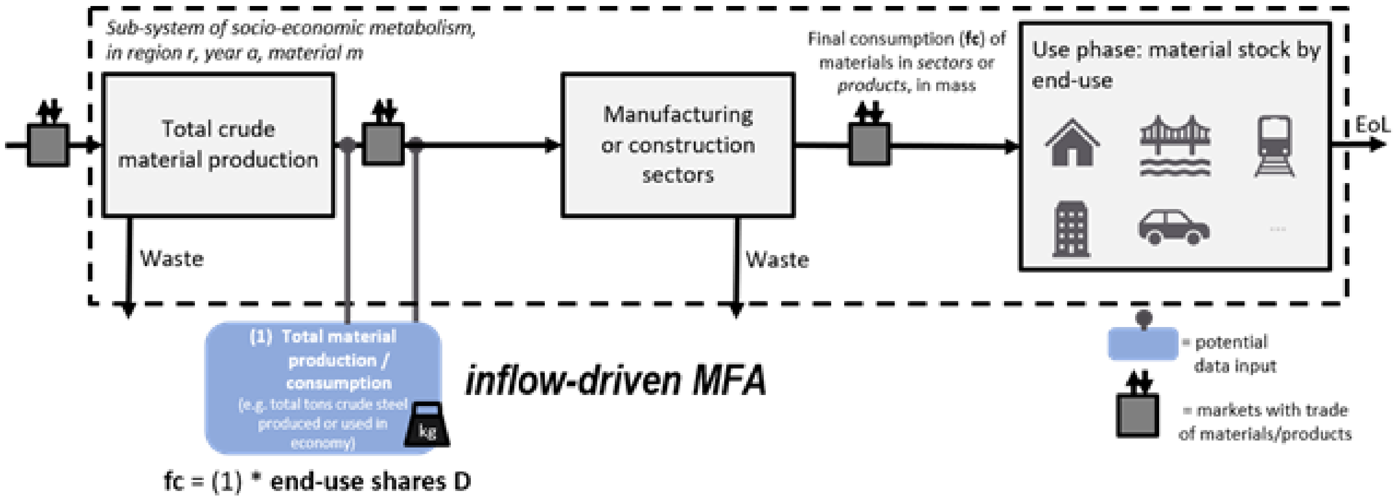
Improved end-use differentiations

- end-use shares split aggregate material flow data to end-use products/sectors



- derived from physical and/or monetary data (*Streeck et al, a,b, in revision*):
  - Industry shipments in physical units scarce
  - Monetary IOTs in combination with enhanced Waste Input-Output (Nakmura et al. 2007) can complement, but show high uncertainty
  - so far: application to U.S. MIOTs 1963-2017 + EXIOBASE3 (maybe extend to GLORIA)

--> + auxiliary statistics could provide ~robust end-use shares with improved material, country and time resolution

--> cross-checking with stock-driven studies might allow for estimating 'hard to quantify' end-uses (e.g. infrastructure, machinery)

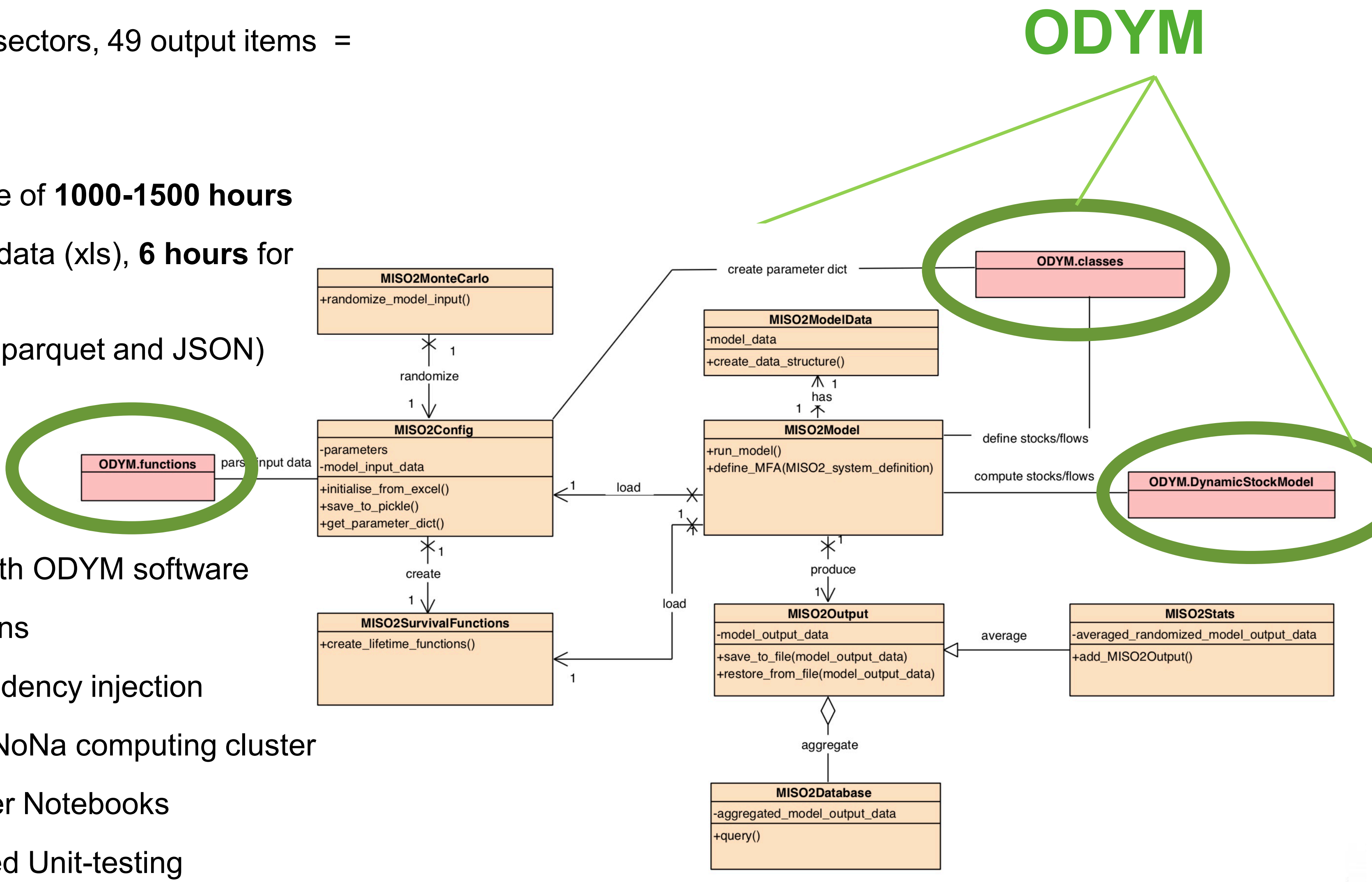
MISO-2 software key data

Project scale

- 179 regions, 23 materials, 218 years, 2 sectors, 49 output items = **~440*10^6 datapoints** (and growing)
- Runtime over all regions: **6-10 minutes**
- 10.000 Monte-Carlo Simulations: runtime of **1000-1500 hours**
- Initialization: **1 hour** for parsing of input data (xls), **6 hours** for precomputation of survival functions
- Output file size of **400-500 MB per run** (parquet and JSON)
- Peak memory use **10-12 GB**

Software architecture

- Object-oriented structure interfacing with ODYM software
- 8 core classes + various helper functions
- Monte-Carlo implementation via dependency injection
- Parallel computing on the university‘s NoNa computing cluster
- Documentation with Sphinx and Jupyter Notebooks
- Comprehensive integration tests, limited Unit-testing



Challenges when building on ODYM to implement MISO-2

- **Scale and efficiency**
  - Design choices limit scalability
  - Trade-off between usability and efficiency
  - MISO2 software approaches scale where distributed computing and/or more efficient implementations are needed
- **Monte Carlo randomization**
  - Limited architecture / interface for dealing with uncertainty
  - Stats-array / uncertainty sheet interface introduce large overhead
- **Model data input / output**
  - Excel human-friendly for preparing model input data, but not machine-friendly choice
- **Minor quirks**
  - as found in any software that is actually used

Next steps for MISO-2 modelling & results database

- **MISO-2 modellling framework**
  - **Refinement:** Efficiency, readability, documentation
  - **Output architecture:** making large-scale data accessible *analysis-ready*
  - **Global sensitivity analysis** of MCS results to understand „sources“ of uncertainty in results

- **Analysis & scenarios 2023+**
  - Stock-flow service relations
  - Wellbeing
  - Decoupling
  - Circular Economy
  - Collaborations? ☺

Thanks for your attention!

Project homepage: **matstocks.boku.ac.at**

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