

Empirical agent-based modelling of circular business models:

incorporating dynamic LCA and MFA from a consumption perspective

ISIE day 2024

R. Koide^{1,2,3}, S. Murakami³, H. Yamamoto¹,
K. Nansai¹, J.N. Quist²

¹ National Institute for Environmental Studies, Japan

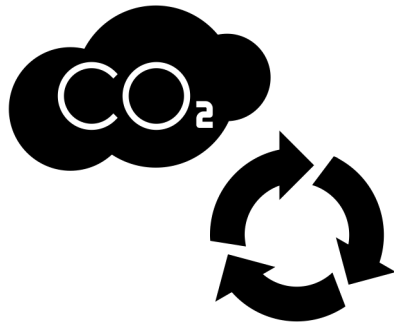
² Delft University of Technology

³ The University of Tokyo



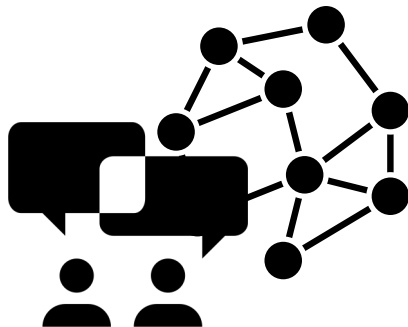
Join at menti.com | use code 8886 3281

Key questions in a transition to a Circular Economy



1. How can we ensure positive sustainability impacts from circular strategies?

Rebound or backfire effects

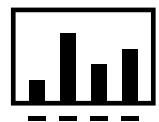


2. How can we diffuse circular business models among consumers?

Lack of consumer acceptance

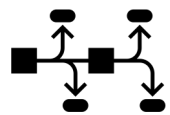
We need an ABM for assessment of circular economy

Mainstream IE methods



Life Cycle Assessment (LCA)

Quantify sustainability impacts

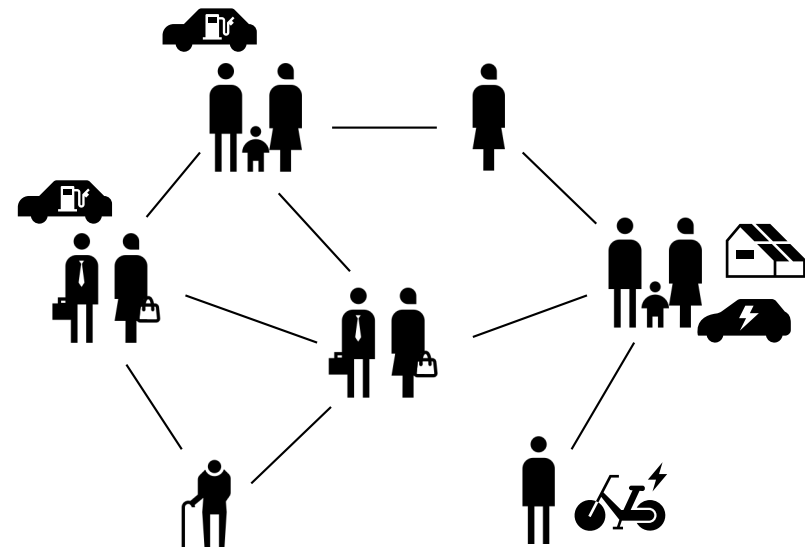


Material Flow Analysis (MFA)

Quantify circularity



Agent-based Modeling (ABM)



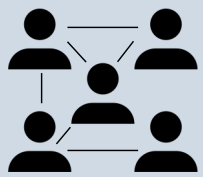
Limitations

- *Static*
- *Retrospective*
- *Aggregated or average*
- *Lack of decision-making model*

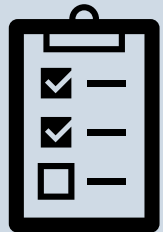
Strengths

- *Dynamic*
- *Prospective & exploratory*
- *Heterogeneity of actors*
- *Modelling decision-making*

Purpose of this study



1. Developing **ABM for circular business models** (7 strategies: e.g., repair, reuse, sharing, leasing, refurbish) with **behavioural science and LCA** (Koide et al. 2023)



2. Propose a **method to parameterise** the behaviour rules of agents using **consumer surveys**



3. Demonstrate **scenario and sensitivity analyses** to understand the dynamics of diffusion, sustainability impacts, and identify critical parameters

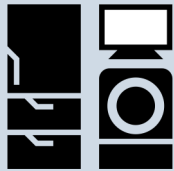
Overview of agents

Households



- Decisions on purchase, repair, disposal of products
- Use products for probabilistic duration
- Influenced through social networks & advertisements

Products



- Probabilistically components broken
- Being repaired, reused, refurbished, upgraded
- Being owned, leased, rented, shared

Supply Chains



Manufacturer



Reuse shop



Provider



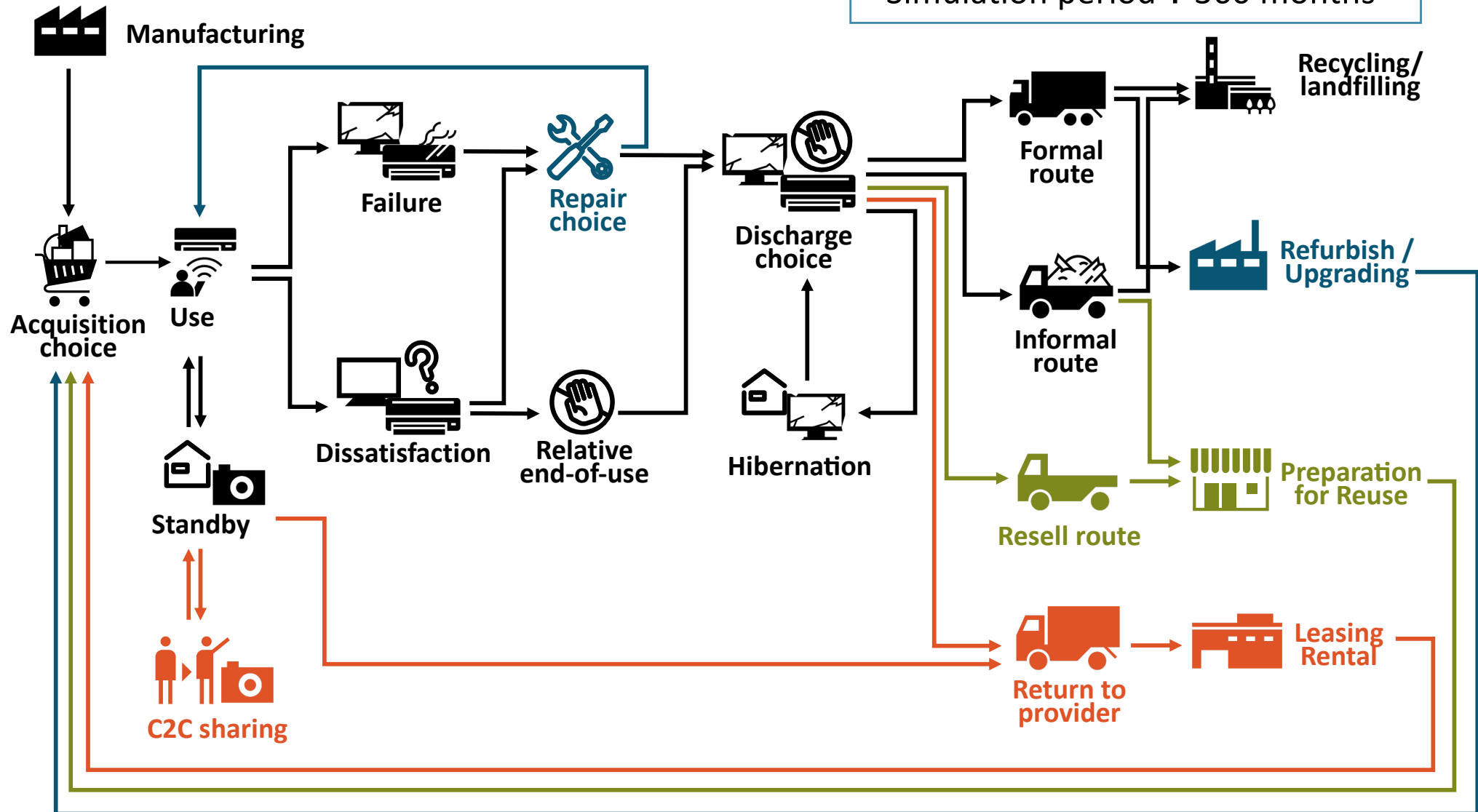
Recycler

- Implement circular strategies
- Manage product stock
- Keep inventory to calculate circularity and environmental impacts

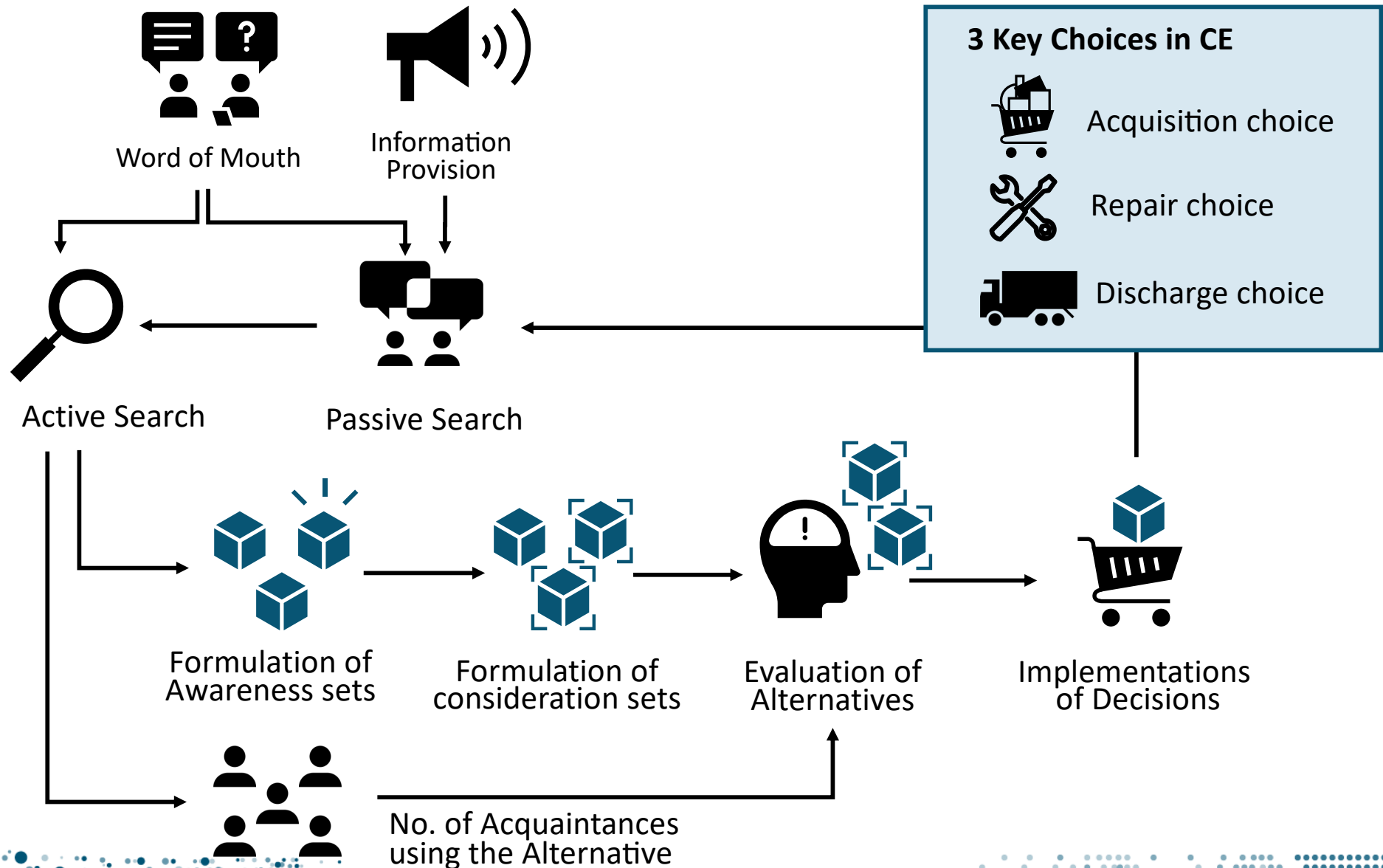
Modelling product circulation

Time step : 1 month

Simulation period : 360 months



Modelling consumer decision-making



Empirical ABM: refrigerator & laptop in Japanese market

Leasing (subscription)
instead of owning



Refurbishment of used products
for owning or leasing



Challenges in empirical data for circular economy ABM



Circular behaviours
are **not observable**
& **public data not**
available



Circular business
models are **not yet**
fully implemented in
real-world



Methods for
empirical CE-ABM
are **not yet**
established

Consumer survey

Demographically representative online survey (Japan)
June 2022 (N=911) & Oct 2023 (N=1023)



AWARENESS AND
KNOWLEDGE OF
CIRCULAR STRATEGIES



PREFERENCES ON NEW
CIRCULAR BUSINESS
MODELS



TYPE OF PRODUCT
PURCHASED



DURATION OF
PRODUCT USE



REASONS FOR END-OF-
USING PRODUCTS



DESTINATION OF
DISCHARGED
PRODUCTS



SOCIAL NETWORK AND
WORD-OF-MOUTH

Data transformation

Survey item

Data transformation

Parameters



Hierarchical Bayes conjoint analysis of circular business models



Part-worth utility



Estimation of consideration costs (Roberts & Lattin model)



Consideration threshold



Parametric proportional hazard model (Weibull distribution and covariates)



Prediction of product use duration



Causal analysis using inverse probability weighting with covariates



Effects of social influence



Multiple-imputation of missing data



Initial state variables

Data transformation

Survey item

Data transformation

Parameters



Hierarchical Bayes conjoint analysis of circular business models



Part-worth utility



110+ Global Parameters

shold



80+ Agent-level Parameters

uct

(1000 Agents x 80 = 80,000+ data points)

uence



Multiple-imputation of missing data



Initial state variables

Scenario analysis

Comparison of 4 diffusion strategies

(marketing 4P + 'prolong')



PRICE

Lower price of
refurbished &
leased products



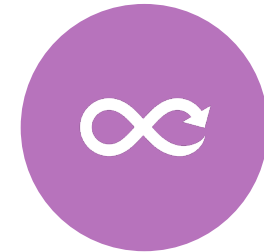
PROMOTION

Advertisements &
recommendation
right at the shop



PRODUCT

Cleaning surface
Functional upgrading
Longer warranty



PROLONG

Durable parts
Longer after-service
Convenience of
repair

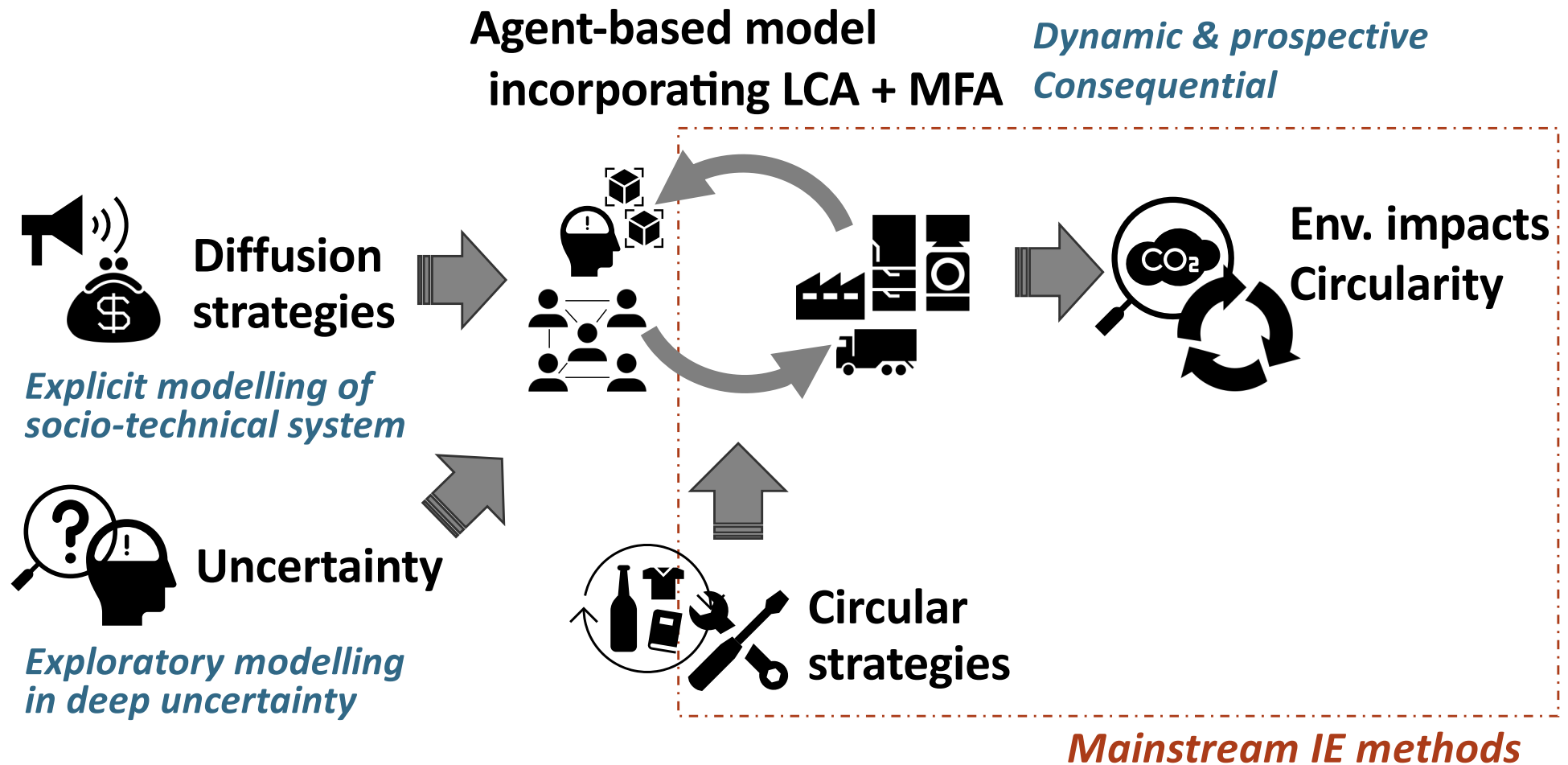
Sensitivity analysis

Morris's elementary effects screening (Morris 1991)

- Global sensitivity analysis method
- Explore the importance of a large number of parameters to a model
- Overall influence of parameters (μ)
- Non-linear or interaction effects (σ)



Takeaways: contribution of ABM in circularity assessment



This work was supported by JSPS Kakenhi [JP24K03152, JP21K12374], ERCA Environment Research and Technology Development Fund [JPMEERF20223001], and Panasonic Holdings Corporation.