A Next-Generation Analytical Approach to Policy Design:
Completely Agent-Based Modeling (c-ABM)

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Virtual Roundtable:
"Next Generation Analytical Approaches to Policy"

Organized by:
The New York University School of Global Public Health;
Organization for Economic Cooperation and Development **(OECD);**
and New Approaches to Economic Challenges (**NAEC**).

Event Date:
21 April 2022

Policy Design for Critical Societal Issues

General Goals: Understand how existing real-world policies

— are *currently* performing;

— could be *designed* to perform *better*.

Any modeling method used to support these general goals must simplify reality; but should nevertheless be **flexible as well as logically rigorous**, permitting:

1) Careful tailoring of model simplifications *to purposes at hand*

2) Dynamic events to be modeled *as open-ended cause-effect processes*

3) Careful matching of modeled agents *to empirical referents*

   Example: **"Human" agents should be permitted "to breathe".**

- **Standard dynamic economic modeling methods:** *do not* permit **1)**, **2)**, and **3)**.

- **Completely Agent-Based Modeling (c-ABM) :** *does* permit **1)**, **2)**, and **3)**.

Completely *Agent-Based Modeling* (*c-ABM*)

https://www2.econ.iastate.edu/tesfatsi/ace.htm

- *Rough Description:* Modeling of real-world dynamic systems as open-ended systems of interacting agents
- *Axiomatic Characterization:* Seven specific modeling principles

Key features and capabilities:

— **Enables "historical" study** of real-world dynamic systems as unfolding sequences of events.

— **Events are fully driven by agent interactions**, starting from initially specified *agent states (i.e., data, attributes, and/or methods*).

— **Agents can be broadly specified** to represent physical, biological, social, and/or institutional entities.

— **Role of the modeler is restricted** to the specification of **initial** agent states, and to **non-perturbational** observation, recording, and analysis of model outcomes. (*culture-dish modeling*)

c-ABM Modeling Principles (MP1) – (MP7)

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(MP1) Agent Definition: An *agent* is a software entity within a computationally constructed world that can affect world outcomes through expressed actions.

(MP2) Agent Scope: Agents can represent a broad range of entities, e.g., individual life-forms, social groupings, institutions, and/or physical phenomena.

(MP3) Agent Local Constructivity: An intended action of an agent at any given instant is determined by the agent's *state (data, attributes, and/or methods)* at this instant.

(MP4) Agent Autonomy: All *agent interactions (expressed agent actions)* at any given instant are determined by the ensemble of agent states at this instant.

(MP5) System Constructivity: The state of the world at any given instant is determined by the ensemble of agent states at this instant.

(MP6) System Historicity: Given an initial ensemble of agent states, any subsequent *world event (change in agent states)* is induced by prior and/or concurrent agent interactions.

(MP7) Modeler as Culture-Dish Experimenter: The role of the modeler is limited to the configuration and setting of **initial** agent states, and to the **non-perturbational** observation, analysis, and reporting of world outcomes.

c-ABM Permits Comprehensive Bottom-to-Top Empirical Validation *Tailored to Policy Purpose*

https://www2.econ.iastate.edu/tesfatsi/EmpValid.htm

EV1. Input Validation

Are the exogenous inputs for a model *empirically meaningful and appropriate for purpose at hand?*

> ***Exogenous Input Examples:*** Initial state conditions, functional forms, shock realizations, data-based parameter estimates, &/or parameter values imported from other studies

EV2. Process Validation

— Do modeled physical, biological, institutional, & social processes *reflect real-world aspects important for purpose at hand?*

— Are process specifications *consistent with essential scaffolding constraints*, such as physical laws, stock-flow relationships, and accounting identities?

EV3. Descriptive Output Validation:

How well are model-generated outputs able to *capture salient features of the sample data* that was used for model identification? (*in-sample fitting*)

EV4. Predictive Output Validation:

How well are model-generated outputs able to *forecast distributions or distribution moments* either for sample data withheld from model identification, or for later acquired data? (*out-of-sample forecasting*)

c-ABM Permits Policy Design for Critical Societal Issues that
Cross Traditional Disciplinary Boundaries

Illustration: **Net-Zero 2050** (International Energy Agency Report, Oct 2021)

Goal: Transform *global energy sector* into a *net-zero CO2 emissions sector by 2050*

Possible Approach: Use c-ABM co-simulation platforms for development and testing of proposed new Electric Power Market Designs

Example: ITD TES Platform V2 (Open Source, Java/Python/C++, GitHub Repository)

— Developed by econ/engineering team at Iowa State U & Pacific Northwest National Lab (PNNL)

— Permits formulation & performance testing of Transactive Energy System (TES) designs as possible pathways to Net-Zero 2050 for electric power systems consisting of Integrated Transmission and Distribution (ITD) systems.

— **Funded by:** U.S. Department of Energy (DOE), PNNL, National Science Foundation (NSF), Sandia National Lab (SNL), Los Alamos National Lab (LANL), Power Systems Engineering Research Center (PSERC, Cornell U), and the Electric Power Research Center (EPRC, ISU)

— https://www2.econ.iastate.edu/tesfatsi/ITDProjectHome.htm

ITD TES Platform V2: Illustrative Implementation

An *I*ntegrated *T*ransmission and *D*istribution (*ITD*) system for which:
 (i) A 123-node distribution network is populated by 927 households;
 (ii) Each household has a *H*eating, *V*entilation, & *A*ir-*C*onditioning (*HVAC*) system;
(iii) Each HVAC system is smartly controlled (i.e., responsive to price signals)
(iv) The 123-node distribution network is linked to an 8-node transmission network

Transmission Level

Linked

Distribution Level
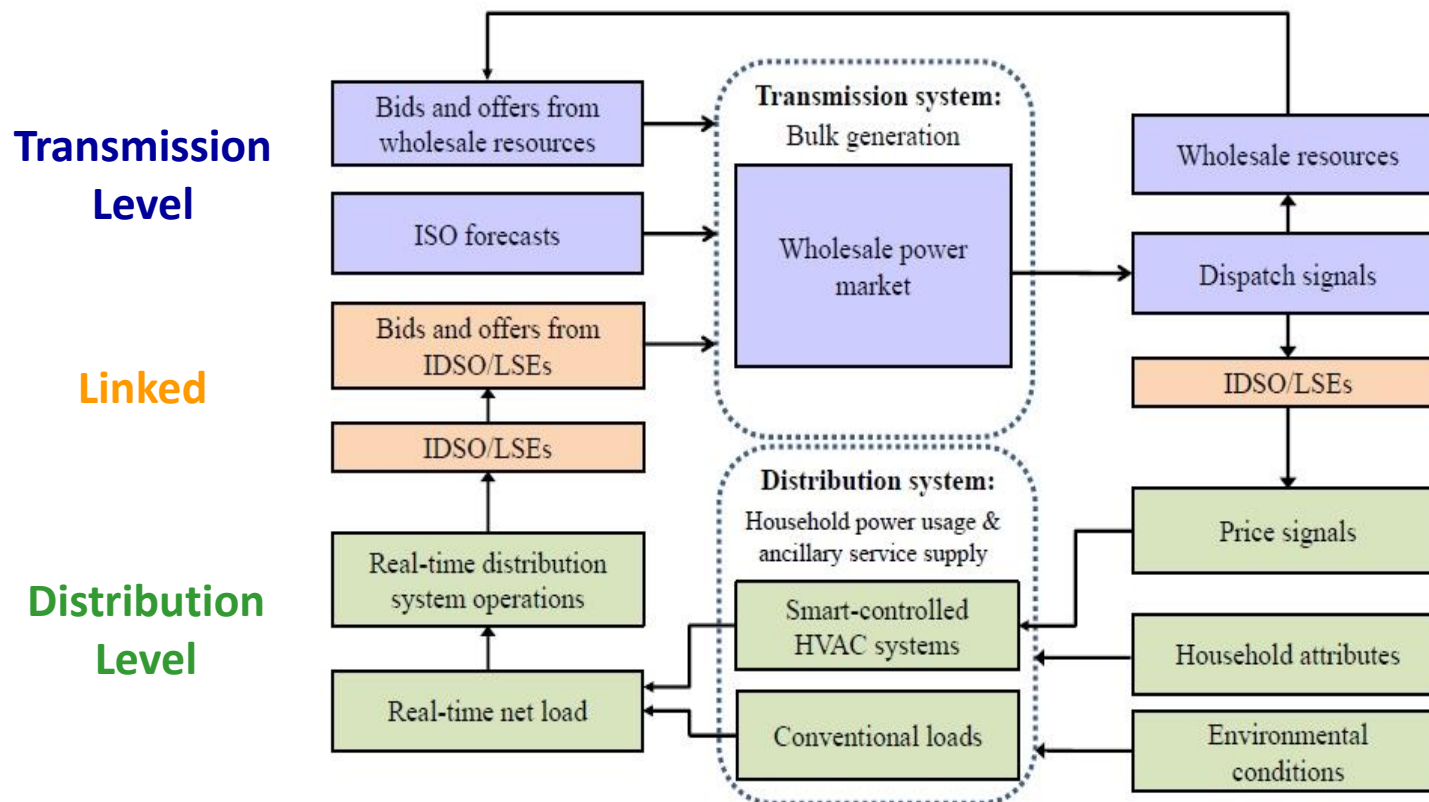
IDSO = *I*ndependent *D*istribution *S*ystem *O*perator (manages distribution system)
 LSE = *L*oad-*S*erving *E*ntity (submits retail customer power demands into wholesale power market)

c-ABM Helps Bridge "Valley of Death" for Policy Design Studies

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Design Readiness Levels (DRLs)

DRL-1: Conceptual design idea

DRL-2: Analytic formulation

DRL-3: Low-fidelity small-scale modeling

Basic research carried out at universities...

DRL-4: Moderate-fidelity moderate-scale modeling

DRL-5: High-fidelity moderate-scale modeling

DRL-6: Pilot study (reflects *expected* field conditions *apart from scale*)

Valley of Death

DRL-7: Prototype large-scale modeling (reflects *expected* field conditions)

DRL-8: Field study

DRL-9: Real-world implementation

Government, business, regulatory agencies …

c-ABM Supports *Iterative Participatory Modeling (IPM)*

Example: IPM for Complex Policy Design Problems

— Researchers & stakeholders join together in a <u>repeated cycling</u> through Design Readiness Levels (DRLs) 1-9, an ongoing open-ended learning process.

— In each cycle, use of a c-ABM platform can help ensure progression thru the **Valley of Death** (**DRLs 4-6**).

Goal: Continual policy improvement rather than the attempted delivery of definitive policy solutions.

c-ABM and 100% Human-Subject Experiments are Boundary Points for
Broad Spectrum of Experimental Methods Suitable for Policy Design

100% human

Humans with computer access

Human-controlled computer avatars

Tethered

Mix of humans and computer agents

Not Tethered

Human-calibrated computer agents

Computer agents with real-world data streaming

100% computer agents evolved from initial conditions **(c-ABM)**
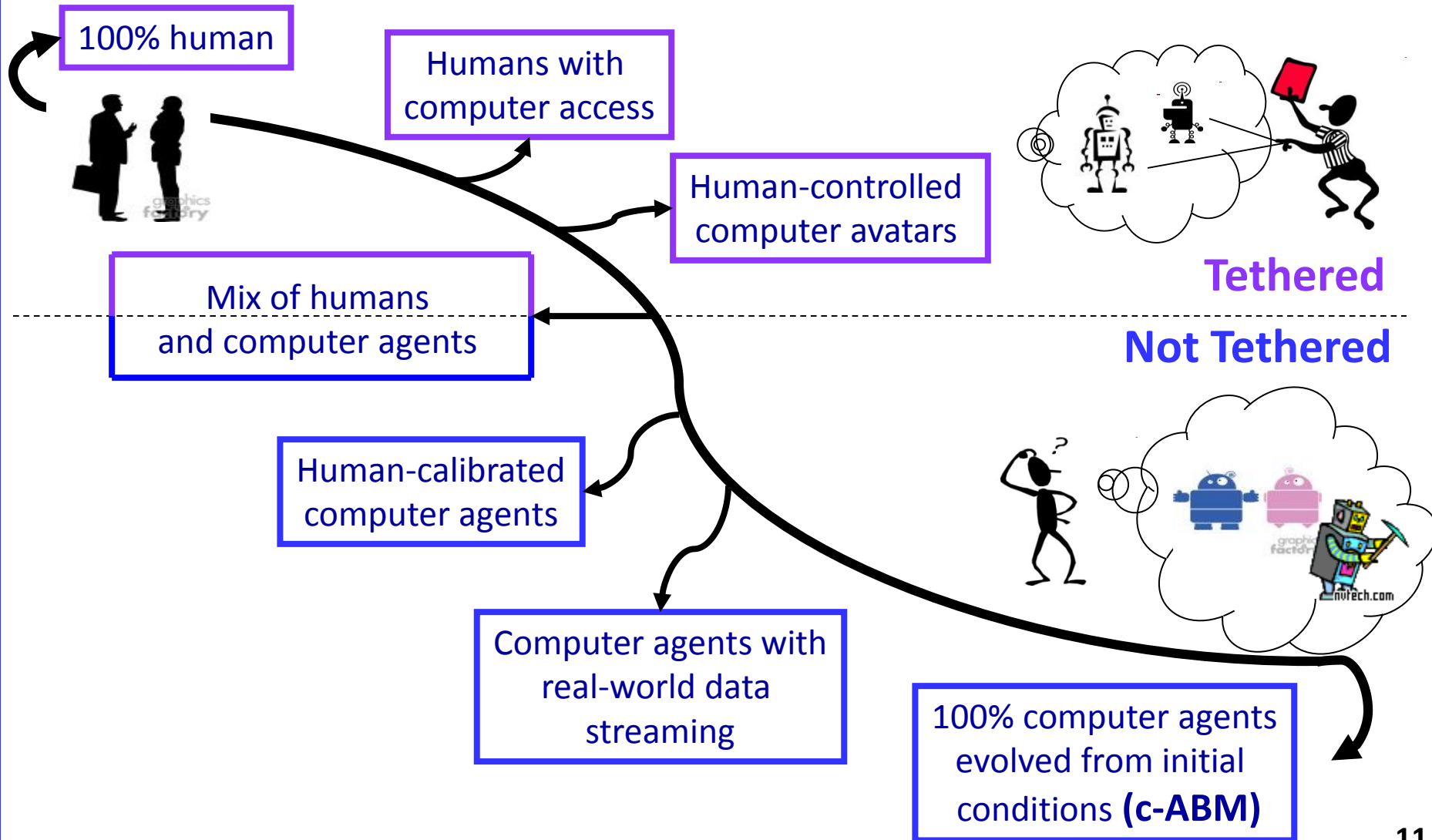
Background Materials (With Links)

— **Agent-Based Computational Economics: A Completely Agent-Based Modeling (c-ABM) Approach**
https://www2.econ.iastate.edu/tesfatsi/ace.htm

— **On-Line Guide for Newcomers to Agent-Based Modeling in the Social Sciences**
https://www2.econ.iastate.edu/tesfatsi/abmread.htm

— **Empirical Validation of c-ABM Models**
https://www2.econ.iastate.edu/tesfatsi/EmpValid.htm

— **Integrated Transmission and Distribution (ITD) Project: ISU Homepage**
https://www2.econ.iastate.edu/tesfatsi/ITDProjectHome.htm

— Leigh Tesfatsion (2021). *A New Swing-Contract Design for Wholesale Power Markets*, 20 Chps., 288pp., John Wiley & Sons (IEEE Press Series on Power Engineering), Hoboken, New Jersey, USA.
https://www2.econ.iastate.edu/tesfatsi/SCBookSlideSetOverview.pdf

— Leigh Tesfatsion (2018) , "**Electric Power Markets in Transition: Agent-Based Modeling Tools for Transactive Energy Support**" (Preprint), Ch. 13 (pp. 715-766) in C. Hommes & B. LeBaron (Eds.), *Handbook of Computational Economics 4: Heterogeneous Agent Models*, Handbooks in Economics Series, North Holland (Elsevier), Amsterdam, the Netherlands.

— Leigh Tesfatsion (2017), "**Modeling Economic Systems as Locally-Constructive Sequential Games,**" *Journal of Economic Methodology*, Vol. 24, Issue 4, pp 384-409
https://lib.dr.iastate.edu/econ_workingpapers/23