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EN-ROADS SIMULATOR SCIENCE

What is En-ROADS?

En-ROADS is a global model that focuses on how changes in the energy, economic, and public policy systems could affect greenhouse gas emissions and climate outcomes. The simulator is used to help people see what it takes to address climate change. Behind the simulator is an extensive study of the literature of important factors such as delay times, progress ratios, price sensitivities, historical growth of energy sources, and energy efficiency potential. En-ROADS stands for *Energy Rapid Overview and Decision-Support.* It was built by a team of modelers from Climate Interactive, MIT, and Ventana System, with contributions from others over the years.

En-ROADS is a high-order, non-linear differential equation **System Dynamics (https://systemdynamics.org/what-is-system-dynamics/)**model that is built in the **Vensim software (https://vensim.com/)**. The code is then translated into **WebAssembly (https://webassembly.org/)** via **SDEverywhere (https://sdeverywhere.org/)** so that it can run in a web browser. The simulator starts in 1990 with a set of initial parameter conditions, and then a set of equations computes all the different variables that you see in the graphs through 2100 when a slider is moved. En-ROADS is powered by ~21,000 equations that provide output in 60 milliseconds with a time step of ~45 days across the time range.

The interface of En-ROADS allows access to the model online in over 20 languages.

Explore the En-ROADS Technical Reference

What are the origins of En-ROADS?

En-ROADS has developed out of years of collaboration between the modeling team at Climate Interactive, the MIT Sloan School of Management's System Dynamics Group and Sustainability Initiative, and Ventana Systems. The simulator grew out of the work this team had done on the **C-ROADS simulator (/c-roads)**, which focuses on the long-term impacts of climate strategies across distinct regional groups. As a result, the origins of En-ROADS can be traced back to the MIT PhD theses of **Dr. John Sterman (/about/staff/john-sterman)** and **Dr. Tom Fiddaman (https://www.ventanasystems.com/employee/thomas-s-fiddaman/)**. Collaboration among this team continues to this day and includes many additional partners, such as the UMass Lowell Climate

Change Initiative, to ensure the model is world-class. Ongoing development of En-ROADS is focused on ensuring that En-ROADS can address important policy questions and make its insights accessible to a wide range of audiences. **Updates (https://docs.climateinteractive.org/projects/en-roads/en/latest/guide/changelog.html)** are released almost every month.

Where does En-ROADS get its data?

The En-ROADS simulator is primarily driven by its own equations, with only a few external datasets, and is calibrated against history and projections. Default values and bounds on economic, energy, and climate related dynamics have been determined from an extensive review of literature. Many of these parameters or assumptions can be changed in the "Assumptions" view under the "Simulation" menu. The details about the underlying equations and parameters are available in the **En-ROADS Technical Reference (/en-roads-technical-reference)**.

En-ROADS incorporates external data in 5 ways:

1. Initial conditions

Each of the model's equations needs an initial value to start from in order to compute the change over time from 1990 onwards. For example, according to the United Nations, there were 5.3 billion people in 1990. We set the 1990 population equal to 5.3 billion in En-ROADS. We do the same thing with other initial conditions, such as atmospheric concentrations of carbon and methane. All of those initial conditions are data that we pull from research sources.

2. Parameters (constants)

Values that are estimated from measured data and are input into the model as key factors in creating equations. One example of this would be the *progress ratio*for different energy technologies. The progress ratio is a parameter that describes how the cost of a technology falls for every doubling of capacity. Two papers by **Junginger et al. (https://www.researchgate.net/publication/48326776_Technological_Learning_In_The_Energy_Sector_Lessons_for_Policy_Indust** and **McDonald et al. (https://www.researchgate.net/publication/4946674_Learning_rates_for_energy_technologies)** informed why we chose 0.8 as the progress ratio for renewables, for example. (This value means renewables become 20% cheaper every time capacity is doubled.)

3. Equations creating the model structure

Although most equations in En-ROADS are written by our modeling team, others are adopted from the work of other researcher teams. For example, in En-ROADS the structure for the carbon cycle (how much CO_2 is in the atmosphere, versus carbon in biomass and humus and in the ocean, and how they flow in between) is adopted from a paper by **Goudriaan and Ketner. (https://link.springer.com/article/10.1007/BF00144611)**

4. Comparison against measured historical data

To improve the model, we **compare our model's results (https://docs.climateinteractive.org/projects/en-roads/en/latest/guide/historical_graphs.html)** against what has actually happened in the real world. Since primary energy demand, CO_2 concentration, temperature, and other values have been measured over the years, we can compare what the model produces from 1990-2020 with its equations to the real-world data and see if they are similar. If the behavior of these variables in En-ROADS matches historical data well, that gives us some confidence that using the same equations could describe what might happen in the future.

We use historical data and then follow a chain of reasoning from known inputs to an intermediate calculation. This process allows us to evaluate subsections of En-ROADS, building up to the full model. For example, given known population and size of the economy, does En-ROADS calculate energy consumption the same as published data? Does the En-ROADS energy price sub-model give the same prices as reported? Does the En-ROADS energy market sub-model give the same mix of energy sources given those prices? And so on, all the way up to matching measured CO_2 in the atmosphere, temperature change, sea level rise, and more.

5. Comparison against other models' future projections

Since En-ROADS is intentionally as simple as possible in order to run very fast and give instant feedback, we compare it to larger, more detailed climate models such as **integrated assessment models (IAMs) (https://esgf-node.llnl.gov/projects/cmip6/)**. These IAM results are collected in a database of scenarios called CMIP6. When En-ROADS is fed the same initial starting conditions (for example, how the economy is going to grow, how population is going to grow, whether there is an additional price on things that emit carbon), we compare its behavior to that of other models. We learn things from what the differences are, and this helps us improve En-ROADS.

Is En-ROADS peer-reviewed?

You can find a **list of our peer-reviewed publications here (/peer-reviewed-research)**. We are currently writing a paper to be submitted for peer review. Once published, we'll notify our users!

En-ROADS is an extension of the **C-ROADS simulator (/c-roads)**, which has gone through a **scientific review process (https://img.climateinteractive.org/2014/01/C-ROADS-Scientific-Review-Summary-1.pdf)** including a **peer-reviewed paper (https://img.climateinteractive.org/2020/06/C-ROADS-ENSO-2013.pdf)**.

How do I learn more about the structure and equations of the model?

The **En-ROADS User Guide (https://docs.climateinteractive.org/projects/en-roads/en/latest/)** is a helpful handbook for the model and covers most of what you would need to know to use it. All assumptions, equations, and parameters are documented in the **En-ROADS Technical Reference (/en-roads-technical-reference)**. If you have a question about the model, be sure to check out the **Climate Interactive Support Desk (https://support.climateinteractive.org/)** – we have a FAQ database of knowledge or our team can help you with a specific question.

To learn more about En-ROADS' model structure and testing, we encourage you to sign up for the free **En-ROADS training. (https://learn.climateinteractive.org/)**

More in-depth videos on En-ROADS model structure and testing (included in the En-ROADS training course):

- **En-ROADS Model Structure (with Professor John Sterman, MIT) (https://youtu.be/djLbVnuWuw8)**
- **How we use research and data in En-ROADS (https://youtu.be/cnxjWE8YhZU)**
- **Comparison to data and others' scenarios (Part 1) (https://youtu.be/TQ5PE-GSN_8)**
- **Comparison to data and others' scenarios (Part 2) (https://youtu.be/kMwRLcI_WQI)**
- **Transparency, model updates, & extreme conditions testing (https://youtu.be/BmHX6L5tbFU)**
- **Relevance to policymakers (https://youtu.be/73dmySpOcyg)**
- **Our top critiques of En-ROADS (with Professor John Sterman, MIT) (https://youtu.be/OAs-ulyzDQ0)**
- **En-ROADS software mechanics (https://youtu.be/y1iupDeoLwQ)**

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