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ADVANCE
Advanced Model Development and Validation for Improved Analysis of Costs and Impacts of Mitigation Policies

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DELIVERABLE No 1.5
Updated model documentation reflecting the state of the models at the end of the project

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ADVANCE – ADVANCED MODEL DEVELOPMENT AND VALIDATION FOR IMPROVED ANALYSIS OF COSTS AND IMPACTS OF MITIGATION POLICIES

PROJECT NO 308329

DELIVERABLE NO. 1.5

Updated model documentation reflecting the state of the models at the end of the project

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1. Introduction

Integrated assessment models (IAMs) and energy-economy models have become central tools for informing decision makers and society at large about the choices for long-term global and regional climate mitigation strategies. There is an increasing demand for improved representations of complex energy, climate and land-use system interactions and thorough validation of model behavior in order to increase user confidence in climate policy assessments. The ADVANCE project responded to this demand by facilitating the development of a new generation of IAMs. In addition, ADVANCE made a coordinated effort on improving model transparency, model validation, and data handling.

The development of a harmonized model documentation is one of the core activities in support of this objective. As a first output, the development status of the IAMs participating in the ADVANCE project was documented in a harmonized way at the beginning of the project (deliverable D1.1). The documentation includes the compilation of aggregated "reference cards", as well as more extensive documentation.

- The "reference cards" are designed to provide a quick overview of the most important model characteristics, in form of bulleted lists and tables. The structure of these 2-page reference cards is identical for all participating models to facilitate an easy comparison of main features across models.
- The comprehensive documentation (approximately 30 pages plus appendices) of all participating IAM also rely on a standardized template, but with sufficient flexibility in order to describe the models' specificities. This documentation elucidates model structure, mathematical formulations, and relevant input data sets.

Technically, both the reference cards and the more comprehensive documentation were implemented using a Wiki platform (initially hosted at UCL) to specify and iteratively develop the models descriptions[1].

Following further model development during the ADVANCE project, the documentation was updated at the end of the project. However, beyond simply updating the documentation of individual models, a public review process was organized to get feedback from the wider IAM community and different user groups of this resource. The review process and the comments received in the review are described in Section 2. Section 3 summarizes the changes made to the harmonized model documentation in response to the review which ultimately led to the publication of a new Wiki site hosted by PBL[2]. Finally, Section 4 concludes and describes plans to continue maintaining and expanding the harmonized model documentation beyond the duration of the ADVANCE project.

[1] https://wiki.ucl.ac.uk/display/ADVIAM
[2] http://themasites.pbl.nl/models/advance/index.php

2. Public review

A central objective of ADVANCE was to provide harmonized documentation that elucidates the structure, assumptions, limitations and input data of all participating IAMs in the ADVANCE project. To make this effort useful beyond the immediate project participants, it was decided to undertake a public review process that involved both the broader modeling community as well as stakeholders interested in model results.

2.1 Review process

The following potential groups of reviewers were identified by the project consortium, including input from its Advisory Board:

- IAM community, via the Integrated Assessment Modeling Consortium (IAMC)
- Other networks of modelers, including the Global Trade Analysis Project (GTAP) and the International Energy Agency's Energy Technology Systems Analysis Program (ETSAP) communities
- Stakeholders, incl. government agencies (e.g., DG Climate)
- Individual researchers familiar with IAMs

An effort was made to reach out to these groups of potential reviewers and encourage them to submit comments between July and October 2015. The Terms of Reference for the public review of the ADVANCE Harmonized Model Documentation can be found in Annex B of this document.

2.2 Review comments

A synthesis of the review comments received during the public review shows that they fall into three broader categories, (i) content of the documentation, (ii) structure of the harmonized documentation, and (iii) technical implementation of the documentation. The main insights from the review can be found below.

Content of documentation

- Require information on data sources
- Provide information on model parameterization in different dimensions (e.g., technologies, efficiency, resources)
- Elevate "water" to be a topic of its own (currently under "other commodities")

Structure of harmonized documentation

- Introduce templates that are specific for certain types of models (e.g., CGE, energy systems model)
- Provide documentation of 'template model' to improve comparability across models (e.g., follow example of IMAGE model)

Technical implementation

- Improve navigation (e.g., have documentation on one page with expandable chapters – like Wikipedia articles, could also be useful for printing)
- Facilitate comparison across models by cross-linking pages on similar topic across models (for both reference cards and documentation)
- Some pages provide inadequate description – strengthen review process
- Facilitate future updates (specification, spatial, sectoral aggregation)

3. Revision and update

Based on these review comments, but also reflecting new model developments that were undertaken over the past few years within the ADVANCE project and beyond, the overall strucutre of the documentaiton – the so-called template – and the technical implementation were updated compared to the first release of the harmonized model documentation in 2013.

3.1 Template

Based on the review comments that relate to the content and structure of the harmonized documentation, the underlying template was modified. Structurally, several modifications were made, on the one hand to improve consistency across multiple models while on the other hand recognizing the need to accommodate different model types under the same template. As a result, the documentation template (see Annex A) was modularized with several sections now being optional as they are only relevant to a specific type of IAM. For example, IAMs based on computable general equilibrium (CGE) models have significantly more detail on the representation of the economy included compared to engineering-type energy systems models. Therefore, a new optional *Macro-economy* section was introduced that is only completed for IAMs that include general equilibrium effects with additional detail covered in subsections for multi-sectoral CGE models. Similarly, not all IAMs include a representation of *Land-use* which again is covered in an optional section for those models that do include it.

Beyond modularizing the documentation template, important changes that were made include the addition of a separate section on *Non-climate sustainability dimensions*. This change reflects the development that many IAMs over the past few years have embedded linkages to other sustainability dimensions into the models, including energy poverty, water, air pollution and health. Also, based on the prominence of the topic in the public discussion surrounding IAM scenarios, a specific subsection dedicated to the representation of *Carbon Dioxide Removal (CDR)* has been added the template.

3.2 Wiki platform

Based on the review comments and additional feedback from the modeling teams that implemented the documentation of their IAM in the previous Wiki platform[3], a set of selection criteria for a new documentation platform was compiled. The criteria are listed below:

[3] Confluence Wiki, see https://www.atlassian.com/software/confluence

- Low overhead for managing platform
- Low entry barrier for modeling teams to implement own documentation
- Navigation across different models ("horizontal linking")
- Cross-linking to models diagnostic exercise which includes input data and diagnostic indicators[4]
- Typesetting equations using mathematical notation (e.g. LaTeX code) instead of having to insert pictures
- Handling different versions of models
- Automatic generation of tables: reference cards for single/multiple models to easily compare across multiple models
- Maintenance beyond ADVANCE project

Following a consultation process within the project consortium, it was decided to migrate the harmonized model documentation to a MediaWiki platform[5]. The main reasons for this decision were the following:

- Significant expertise by the project partner PBL with operating and maintaining MediaWiki platforms
- Offer to continue hosting and maintaining the platform beyond the duration of the project by project partner PBL
- Significant experience of multiple IAM groups within ADVANCE as well as from outside the consortium using MediaWiki for their own documentation or other material (in addition, it is worthwhile noting that MediaWiki is also the platform hosting the Wikipedia)
- Availability of many extensions for MediaWiki to allow typesetting equations, citation management, generating dynamic tables, etc.

After the migration of the existing material from the UCL hosted Atlassian Wiki to the PBL hosted MediaWiki, individual modeling teams reviewed the documentation to correct for errors in the semi-automated migration process and revised the documentation to reflect the changes made to the models since the original implementation from 2013. Table 1 below lists the IAMs that to date have completed the reference cards (RF) and full documentation (FD) in the new Wiki platform.

Table 1 Existing harmonized model documentation by ADVANCE project partners in the Wiki. Note: RF = Reference Card, FD = Full Documentation.

Model	Institution	Country	RC	FD
AIM/CGE	National Institute for Environmental Studies (NIES)	Japan	X	X
DNE21+	Research Institute of Innovative Technology for the Earth (RITE)	Japan	X	X
GEM-E3	Institute of Communication And Computer Systems (ICCS)	Greece	X	X

[4] ADVANCE diagnostic database: https://tntcat.iiasa.ac.at/ADVANCEWP1DB
[5] https://www.mediawiki.org

IMACLIM	Centre international de recherche sur l'environnement et le développement (CIRED)	France	X	X
IMAGE	Ministerie Van Infrastructuur En Milieu (PBL)	Netherlands	X	X
iPETS	National Center for Atmospheric Research (NACR)	USA	X	
MESSAGE-GLOBIOM	International Institute for Applied Systems Analysis (IIASA)	Austria	X	X
POLES	JRC - Joint Research Centre - European Commission (IPTS)	European Commission	X	X
REMIND	Potsdam Institut für Klimafolgenforschung (PIK)	Germany	X	X
TIAM-UCL	University College London (UCL)	UK	X	X
WITCH	Fondazione Eni Enrico Mattei (FEEM)	Italy	X	X

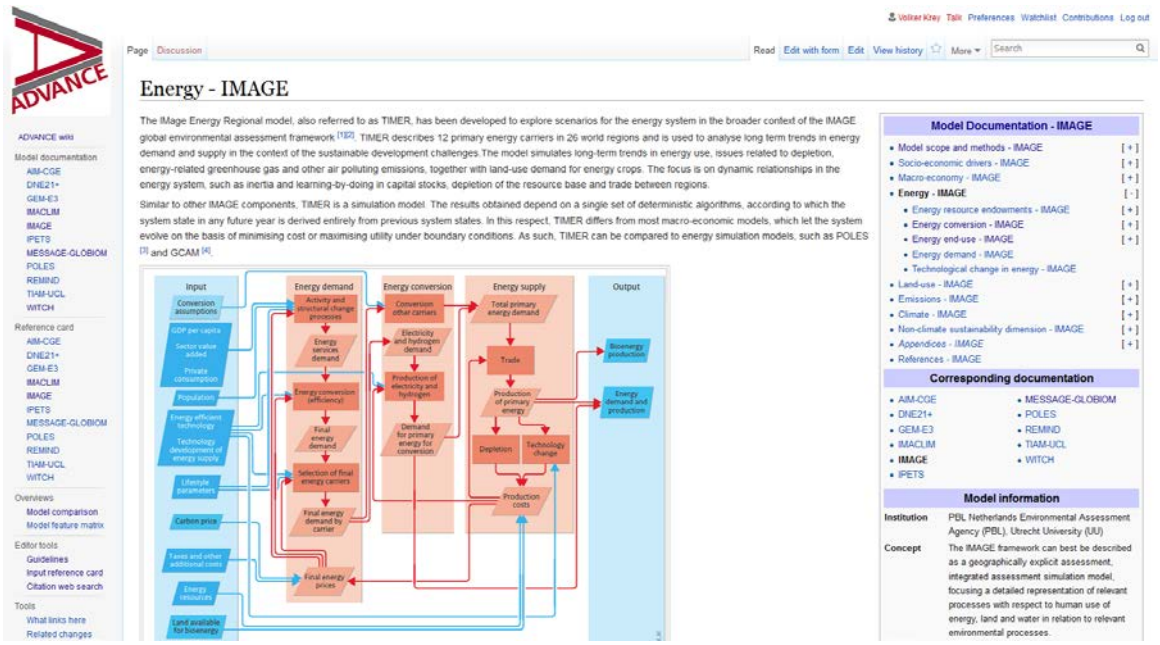

Figure 1: Screenshot of harmonized model documentation developed within the ADVANCE project. Available at http://themasites.pbl.nl/models/advance/index.php.

4. Summary and outlook

A considerable investment was made into the new documentation platform hosted by PBL which also implied an additional effort of individual modelling teams to migrate and update their documentation at the end of the ADVANCE's projects lifetime. Therefore, the ADVANCE consortium approached the steering committee of the Integrated Assessment Modeling Consortium (IAMC) to discuss the possibility of continuing to operate the harmonized documentation platform under the umbrella of the IAMC. Following initial elaborations within the steering committee the proposal was presented at the 9th IAMC annual meeting which took place from 5-7 December 2016 in Beijing and was positively evaluated. In addition, several modelling teams expressed of

interest to add their own models to the harmonized documentation. Therefore, a process within the IAMC's scientific working group on data protocols and management was started to organize the transition to an IAM community resource. The relevant points that will need to be clarified in this context include

- identifying a name for the IAM harmonized model documentation,
- setting up a web-address corresponding to the final name of the harmonized model documentation,
- designing a process for adding new models to the model documentation platform,
- designing and implementing a review process for adding new and updating existing model documentation to ensure high quality standards, and
- adding an unambiguous citation option for the model documentation (e.g., using digital object identifiers – doi's).

It is expected that these steps will be completed over the first half of 2017.

A. Model documentation outline

1. Overview
    - Provide a general overview of how the model is structured, including links to the relevant section on model scope and methods, socio-economic drivers, economy (if relevant), energy, land use (if relevant), emissions, climate (if relevant) and non-climate sustainability dimensions (if relevant).
    - Include a flow chart or similar that shows the basic building blocks of the model and how they interact with each other.
2. Model scope and methods

    2.1. Model concept, solver and details
    - Describe the general concept of the model (e.g., model family, including optimization vs. simulation, representation of sectors and level of detail such as energy, land use and water.
    - Which "intratemporal" equilibrium concept is used (e.g., partial equilibrium, general equilibrium)? Are demands elastic or inelastic?
    - Which intertemporal equilibrium approach is used (e.g., perfect foresight, dynamic recursive/myopic)? In case of a myopic model, how are expectations about the future handled (e.g., "no expectation formation about future prices and capital returns" or is there some information available)?
    - How is uncertainty treated in the model?

    2.2. Temporal dimension
    - What is the base year, time horizon, time step and does the model have foresight (see also Section 1.1 above)?
    - Is any sub-annual time resolution represented in the model?
    - What type of discounting is applied (e.g., in annualizing investment costs, possibly in intertemporal decision-making)?

    2.3. Spatial dimension
    - Is it a global, regional or national model? How many regions are represented?
    - How do regions interact, e.g. trade (if yes, which goods), technology spillovers?
    - Are downscaling tools integrated to the model?

    2.4. Policy
    - Which types of policies are represented in the model?

- How are policies modelled (e.g., renewables subsidies or air pollution policies)?

3. Socio-economic drivers

3.1. Population

- Which demographic projections are used?
- How is the model driven by demographic development?

3.2. Economic activity

- Which economic projections are used and what are the basic drivers of economic development (e.g., TFP, labor productivity growth)?
- How is the model driven by economic activity?

4. Macro-economy [optional]

- Describe in broader terms how is the economy represented.

3.1. Production system and representation of economic sectors [optional]

- How many markets and sectors? Which market regime are considered (perfect competition, oligopoly etc.)? How are prices determined?
- Households
  - Representative or heterogeneous households (income classes), utility function
- Public Sector
  - Exogenous/Endogenous, public/budget, fiscal tools
- Which product varieties/qualities/attributes are represented? Is firm heterogeneity represented?
- Numeraire

3.2. Capital and labour markets [optional]

- Which assumptions on capital/labour mobility are made?
- How are capital vintages represented (e.g., putty-putty, putty-clay)?
- Is involuntary labour unemployment represented? Are labour skills differentiated?
- How are investment decisions made? Are idle capital resources represented?
- Macro closure : Mechanism that equilibrates investments with savings

3.3. Monetary instruments [optional]

- Which monetary instruments are represented (e.g., exchange rate, interest rate (both representation (i.e. exogenous) and values)

3.4. Trade [optional]

- How is trade represented? Armington (imperfect substitutes), Melitz (product differentiation), traded non traded sectors

3.5. Technological change [optional]

- Does the model include technological change in the economy and if so how is it incorporated e.g. exogenous, endogenous, Is R&D included (exogenous, endogenous)?

4. Energy
    - Describe in broader terms the general characteristics of the model's energy system representation and how the flow of energy is handled. In particular, discuss the substitutability of primary energy sources to produce secondary energy carriers, of secondary energy carriers to deliver final energy and ultimate energy services, and whether energy service demands are elastic or inelastic.

4.1. Energy resource endowments

1. Fossil energy resources
2. Uranium and other fissile resources
3. Bioenergy (e.g. bioenergy supply curves, linkage to land-use model)
4. Non-Biomass Renewables

4.2. Energy conversion

1. Electricity
2. Heat [optional]
3. Gaseous fuels (incl. hydrogen) [optional]
4. Liquid fuels [optional]
5. Solid fuels [optional]
6. Grid, pipelines and other infrastructure
    - including systems integration of variable renewable energy sources

4.3. Energy end-use

1. Transport
    - Representation of freight and passenger travel activity, different modes, technologies and costs of transport, modal shifts, technology change
2. Residential and commercial sectors
    - Representation of end use service demand and end use technologies, buildings(e.g. different building ages and types), sub sectors (e.g. residential, commercial or even more specific), explicit efficiency options included (e.g. increased wall insulation, insulated glazing etc).
3. Industrial sector

- Representation of industrial sectors (how are sectors aggregated?), product demand, specific industrial processes and technology availability, cost and transition.

4. Other
   - Are there any other end-use sectors explicitly modelled?

4.4. Energy demand
- Which energy demand types are represented (final energy, useful energy, energy services)?
- How are energy demands linked to the demand drivers?
- Are behavioural aspects included in the demand modelling?

4.5. Technological change
- Does the model include technological change in the energy sector and if so how is it incorporated e.g. learning-by-doing (exogenous, endogenous), is R&D included (exogenous, endogenous)? Representation of inertias and path-dependencies, e.g. via capacity stocks, knowledges stocks, constraints of the expansion and decline of technology deployment, early retirements of fossil energy technology capacities

5. Land-use [optional]
   - Describe in broader terms the general characteristics of the model's land use system representation and how the flow of agricultural and forestry commodities is handled. In particular, discuss whether commodity and/or service demands are elastic or inelastic.

5.1. Agriculture [optional]
- Crop production
- Livestock production

5.2. Forestry [optional]
- How is the forestry sector modelled?

5.3. Land-use change [optional]
- How is land-use change represented in the model?

5.4. Bioenergy [optional]
- How is the production of bioenergy represented in the model?

5.5. Other [optional]
- Any other land uses?

5.6. Demand [optional]
- Which types of demands are included on the land-use side (e.g., food, timber, ecosystem services)?
- How are energy demands linked to the demand drivers?

- Are behavioural aspects included in the demand modelling?

5.7. Technological change [optional]

- Does the model include technological change in the land-use sector and if so how is it incorporated e.g. learning-by-doing (exogenous, endogenous), is R&D included (exogenous, endogenous)? Representation of inertias and path-dependencies, e.g. via capacity stocks, knowledges stocks, constraints of the expansion and decline of technology deployment

6. Emissions

6.1. GHGs

- What gases are included in the model and how are they linked to technologies and economy?

6.2. Pollutants and non-GHG forcing agents [optional]

- What other emissions are included in the model (e.g. NOx, SOx, black and organic carbon, VOCs etc)? Are they endogenous to the model (and if yes, how are they modelled) or projected exogenously?

6.3. Carbon dioxide removal (CDR) options [optional]

- Which CDR options are represented in the model (incl. links to the sections that list/describe these options)?

7. Climate [optional]

7.1. Modelling of climate indicators

7.2. Climate damages, temperature changes, description of module [optional]

8. Non-climate sustainability dimension [optional]

8.1. Air pollution and health [optional]

8.2. Water [optional]

8.3. Other materials, etc. [optional]

- How are other commodities and resources such as water, materials and CCS storage treated?

8.4. Other [optional]

- Are any further non-climate sustainability dimensions covered? – add one subsection per dimension

9. Appendices [optional]

9.1. Appendix 1: Mathematical model description

- Mathematical appendix on model equations and algorithms

9.2. Appendix 2 : Data

- Data used in the models

B. Public Review: Terms of Reference

Background

Integrated assessment models (IAMs) and energy-economy models have become central tools for informing decision makers and society at large about the choices for long-term global and regional climate mitigation strategies. There is an increasing demand for improved representations of complex energy, climate and land-use system interactions and thorough validation of model behavior in order to increase user confidence in climate policy assessments. The ADVANCE project, sponsored by the European Commission under its 7th Framework Programme, responds to this demand by facilitating the development of a new generation of IAMs. In the past, methodological innovations and improvements in IAMs and their application to policy making were hindered by the difficulties in communicating complexities in modeling and data approaches. The ADVANCE project is trying to make a coordinated effort on improving model transparency, model validation, and data handling.

A central objective of ADVANCE is to provide harmonized documentation that elucidates the structure, assumptions, limitations and input data of all participating IAMs in the ADVANCE project. To make this effort useful beyond the immediate project participants it was decided to start a review process that involves both the broader modeling community as well as stakeholders interested in model results. Beyond the review process, it is planned to invite other modeling teams to also provide their model documentation in the harmonized format developed by the ADVANCE project consortium. So far, documentation for eight models is available and listed in Table 1 below.

Objectives

As part of a consultation process with stakeholders involved in the ADVANCE project, it was decided as a first step to develop documentation at two levels of aggregation. It was envisaged that this approach would be particularly helpful for policy makers and other users of model results in understanding key differences between modeling approaches and the representation of different sectors in IAMs. It thus needs to be emphasized that this documentation was not designed to provide information at a level that would enable other researchers to rebuild models and reproduce the results of existing scenarios. However in principle, the current structure of the harmonized model documentation allows for providing extra information as part of appendices describing a model's mathematical formulation and input data, although no effort has been made to harmonize the extent or format to which such information is provided. Developing a documentation standard that would include model code as well as input datasets is a potential follow-up activity.

The two levels of aggregation for model documentation are described as:

- "Reference cards" which are designed to provide a quick overview of the most important model characteristics, in the form of bulleted lists and tables. The

structure of these 2-page reference cards is identical for all participating models to facilitate an easy comparison of main features across models. The key aim of the reference cards was for an accessible document to provide insight for decision makers.

- More comprehensive documentation (some 30 pages) that use a standardized but flexible template, to describe the models' specificities. This documentation elucidates model structure, mathematical formulations, and to some extent relevant input data sets. In addition, there is the possibility to include appendices with more detailed information on, for example, mathematical formulations and data sets used. The audience for the documentation is energy-land-climate modelers, technical staff in government and firms, and PhD students and postdoctoral researchers new to the field.

The initial implementation of the documentation is based on a Wiki format (hosted by the ADVANCE partner University College London, UCL at https://wiki.ucl.ac.uk/display/ADVIAM/Models). The Wiki format was chosen so that changes can be made continuously to reflect model development beyond its current state. Figure 1 provides an overview of the Wiki's layout and hierarchical structure.

Table 1 below lists the models for which the harmonized Wiki documentation is currently available. Several other modeling teams associated with the ADVANCE project have also expressed an interest to provide model documentation in the some structure so the Wiki page has been set up to facilitate additional model descriptions.

Review Process

The review covers the documents that describe the structure of the harmonized model documentation for the reference cards and the 30-page documentation as well as the sample implementations by individual modeling teams. With this in mind the ADVANCE consortium seeks input on the following points:

- Is the overall structure of the reference cards and the 30-page documentation adequate for the target audience?
- Are there any important topics and lists that are key for interpreting model behavior from a high level perspective that are missing in the reference cards?
- Are there any important sections/subsections missing in the 30-page documentation?
- In the sample implementations, should some topics be expanded or reduced in scope given the length limitations? If a sample implementation by a modeling team (overall or in a specific section) seems particularly well laid-out/put together, please highlight this.

- Is it useful to further harmonize/standardize the content of the 30-page documentation under additional headings, keeping in mind that model paradigms and structures are very heterogeneous?
- Is the Wiki format appropriate for providing model documentation of this sort or are reports, manuals or still other ways of publication preferred?

The comments directly relevant to the harmonized Wiki documentation will be used to inform a revision of the documentation structure, implementation and publication medium (Wiki vs. other options) in 2016. ADVANCE will also offer modeling teams that are non-consortium partners to include their harmonized model documentation in the ADVANCE Wiki. Beyond specific comments on the existing documentation within the scope it was designed for, comments on developing the area of harmonized model documentation further are also welcome. The latter will be used to inform further discussions on the topic of harmonized model documentation, but will not be able to be directly reflected in the revision of the harmonized model documentation within ADVANCE.

Review comments should be sent via e-mail to advance-review@pik-potsdam.de by **15 October 2015**.

The ADVANCE Consortium.