Analysis of the European energy system
under the aspects of flexibility and technological progress

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Deliverable

D4.2: Expert Workshop on Energy System Modelling with special focus on system flexibility

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1.0	18.12.2017	Steffi Schreiber	Final version

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1. Short description of the event

On 8th November 2017, the REFLEX consortium organised an expert workshop about 'Technological Learning in the Energy Sector – Implementation of experience curves in energy system models for future cost estimations and environmental impact assessment' in Karlsruhe, Germany. This workshop combined two workshops, which were planned in REFLEX: The Expert Workshop on Energy System Modelling with special focus on system flexibility (Work Package 4) and the Expert Workshop on Experience Curves (Work Package 3). A detailed description about the sessions addressing the topics deducing experience curves are presented in deliverable D3.1 (Report on Expert Workshop on Experience Curves)[1]. The following document is based on deliverable D3.1 and gives a closer look on the second parallel session about implementation of experience curves in energy system models in section 1. Section 2 displays the invitation, while section 3 reports the participation list and section 4 represents the agenda.

The objectives of the workshop were:

- to disseminate and discuss preliminary findings of the REFLEX project 'Analysis of the European energy system under the aspects of flexibility and technological progress';
- to discuss, with experts the methodology and applications of experience curves;
- to discuss, with experts the implementation of technological learning in energy system models; and
- to present proposed methods to apply technological learning for (ex-ante) environmental impact assessment.

Invitations to the workshop were distributed by email to contacts of all REFLEX partners, and were sent to researchers in the fields of experience curves, energy modelling and environmental assessment. Furthermore, personal contacts from various stakeholder groups (business, policy) were invited. The invitation that was sent to the intended participants is shown in Figure 3 below. When registrations were closed, over 40 people had registered for the workshop. 34 people attended the workshop, of which 20 were from external organisations.

The workshop consisted of three parts: a plenary session before lunch (09:00-12:30) and parallel discussion sessions after lunch (13:30-16:00) and a wrap up presentation where key findings from the discussion sessions were presented (16:00-16:20).

The plenary session started with a presentation by Dominik Möst (TU Dresden) welcoming the participants and introducing the REFLEX project's organisation and overall goals. Afterwards, Martin Junginger (Utrecht University) gave an overview of the aims and preliminary findings of REFLEX. After these introductory presentations, six presentations were given by a mix of external and internal keynote speakers. Oliver Schmidt (Imperial College London) presented his work on experience curves for electricity storage technologies. Ulrich Reiter (TEP Energy GmbH) presented the work of TEP Energy on experience curves and technological learning for demand side

[1] For more detailed information about the workshop, please see Deliverable D3.1.

management (DSM) and other tertiary sector technologies. Uwe Remme (IEA) presented an overview of the work of IEA's ETP group on energy modelling and experience curves. Stephanie Heitel (ISI) presented a case study of applying experience curves in the transport model ASTRA. Atse Louwen (UU) presented his work on applying experience curves for environmental impact assessment of PV systems. Finally, Clas-Otto Wene (Chalmers) presented his work on 'Quantum Modelling of the Learning Curve'.

After lunch, the event was split in three parallel discussion sessions focused on

1) the methodology and application of experience curves,
2) the implementation of experience curves in energy models, and
3) the application of experience curves for environmental impact assessment.

In the first parallel session, Noah Kittner (UC Berkeley) presented his work on two-factor experience curves for energy storage technologies, and Thomas Martinsen (Norwegian University of Life Sciences NMBU) presented on the exchange between markets, spill-over and radical innovations and technological learning and experience curves.

In the **second parallel session**, Steffi Schreiber (TU Dresden), Tobias Fleiter (Fraunhofer ISI), Katrin Seddig (KIT-IIP), and Christoph Fraunholz (KIT-IIP) all presented case studies and experiences of implementing learning curves in the energy models ELTRAMOD (electricity supply), FORECAST (buildings and industry), TE3 (transport) and PowerACE (electricity market), respectively. After the four impulse presentations the discussion round was opened. The participants were divided into two groups. One group discussed the challenges of implementing learning curves into simulation models and the second group the challenges and their possible solution for optimisation models.

Hence, a number of key issues about model implementation of experience curves were identified (Figure 1).

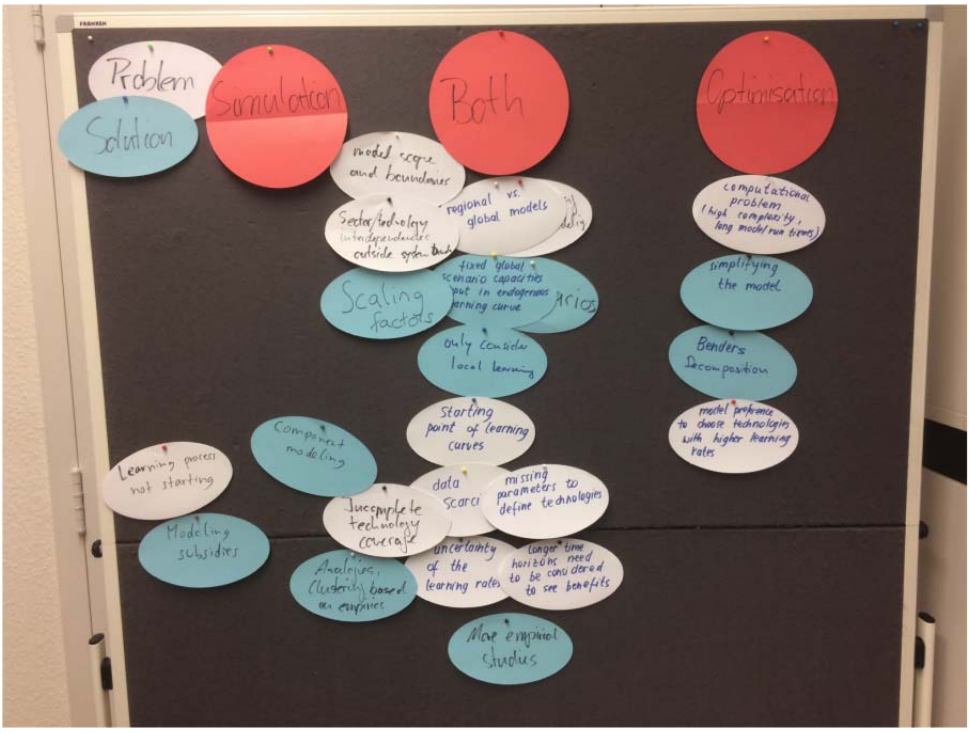

Figure 1: Challenges and solutions of implementing experience curves into different energy system models

For **optimisation models**, an issue is that the models tend to choose technologies with high learning rates, as these models by definition have 'perfect foresight'. Further, optimisation models have problems including non-linear functions (as the learning function). To find a global optimal solution in an optimisation model, the problem needs to be convex. However, the characteristics of learning curves lead to a non-linear and non-convex optimisation problem. Therefore, a global solution cannot be guaranteed. Steffi Schreiber from TU Dresden presented one approach for solving this problem in the second parallel session. The approach describes a linearisation of the non-linear and non-convex problem and is based on Barreto 2001[2] (Figure 2). In a first step, the cumulative cost curve (which is the integral of the specific cost curve) has to be defined (Figure 2.a). Out of the cumulative cost curve the investment costs can be computed (Figure 2.b). In a further step the interpolation of the cumulative cost curve follows by defining the maximum cumulative capacity and by specifying the number of segments (Figure 2.c). This piece-wise approximation of the cumulative cost curve can be transformed into the step-wise approximated learning curve which changes the optimisation problem into a linear and convex problem that can be solved within an optimisation model (Figure 2.d).

[2] Approach presented by Barreto, L. (2001): Technological Learning In Energy Optimization Models And Deployment Of Emerging Technologies, Diss., ETH Zürich.

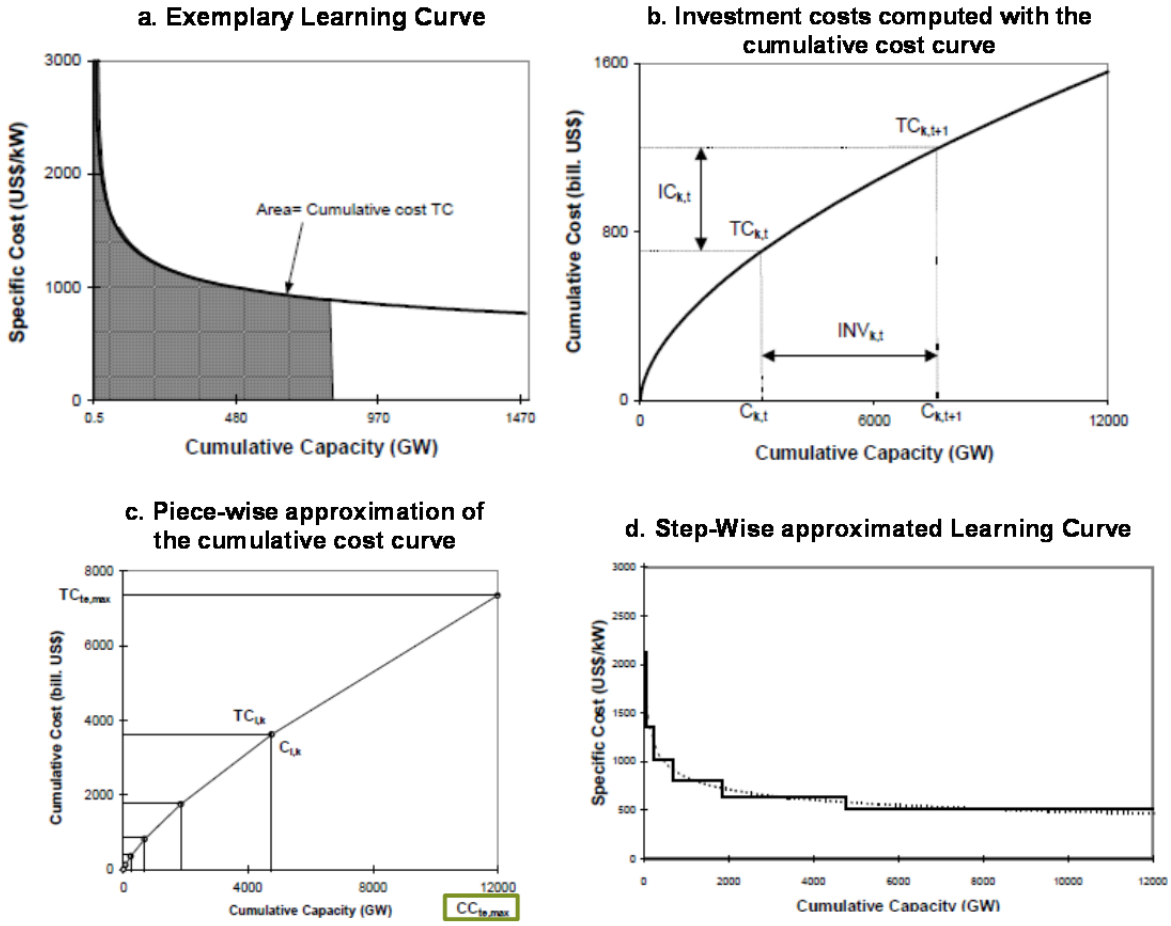

Figure 2: Linearisation of a non-linear and non-convex optimisation problem (Barreto 2001)[2]

In **simulation models** technologies might never start their learning process, although in the long-term they might be very promising. Including policy instruments in the model can address this issue.

Other challenges are relevant for **both types of models**. This includes the lack of empirical data. For many technologies hardly any data on learning rates is available, while for others data quality is not sufficient. Obviously this can be addressed with more empirical research. Empirical research should also provide generic rules that can be used by modellers to make consistent learning assumptions on learning rates. Geographical scale of energy models raises the issues of how to integrate global technological learning in regional/local models. In this sense, sectoral models also have problems including cross-sectoral learning. Scaling factors and (exogenous) global scenarios were mentioned as possible solutions.

In the third parallel discussion session, Atse Louwen (UU) and Lei Xu and Mary Fuss (KIT-ITAS) gave presentations about ex-ante environmental impact assessment, respectively by using experience curves and updating of Lifecycle Inventories. In each of the parallel sessions, presentations were followed (and alternated) by open discussions with the participants.

Finally, the workshop concluded with a wrap-up session, where key findings and discussion points of the parallel discussion sessions were summarised and presented to all workshop participants, before closing of the workshop.

By assembling researchers and experts from the fields of experience curves and energy modelling, interesting state-of-the-art presentations, fruitful and helpful discussions took place. Many participants were very positive about the workshop content and outcomes, and mentioned that they had struggled with many of the questions addressed, but had been missing a forum like this to discuss them. Furthermore, important insights were acquired that will be applied in REFLEX. The workshop-format based on keynote speeches in the plenary session, impulse presentations in the parallel sessions, including time for discussions was a good basis for an intensive and productive exchange between participants.

The presentations from the workshop are available on the REFLEX website (http://reflex-project.eu/public/).

2. INVITATION

2nd WORKSHOP ANNOUNCEMENT and CALL FOR CONTRIBUTIONS

Technological Learning in the Energy Sector

Implementation of experience curves in energy system models for future cost estimations and environmental impact assessment

New technologies -- such as photovoltaics, electric vehicles, heat pumps, and batteries -- are entering the energy markets and systems at unprecedented rates. Questions arise such as: when will these technologies achieve which levels of maturity? And at what cost levels and which points in time can they be competitive in which market segments?

Experience curves are one possibility to assess the future cost of technologies. The REFLEX project is devising experience curves for a large number of energy technologies. These technologies include traditional and upcoming energy supply technologies, but also new technologies that enable high levels of flexibility in electricity grids. The devised experience curves will be implemented in a variety of energy systems models, covering various sectors such as energy supply and demand, transportation, and heat.

The REFLEX consortium is hosting an expert workshop on November 8th, where state-of-the-art experience curves will be presented and methodological issues of implementing experience curves in energy systems models will be addressed. Furthermore, the workshop will analyse the application of experience curves for prospective environmental impact assessment.

The REFLEX consortium is kindly inviting you to attend our workshop. Registration is free of charge. Please register via the link below before October 15th, 2017.

We are furthermore calling for experts in the field of experience curves, energy system modelling and related areas to contribute by means of oral presentations. If you would like to contribute, register via the link below before October 1st, 2017.

Register here:
https://goo.gl/forms/bXti1rnBKSTsrp2t2

Date

Wednesday November 8th 2017
from 09:00h - 17:00h

(on Tuesday November 7th at 19:30 we host a social dinner at own expense)

Location

Karlsruhe, Germany
(for more information see next page)

Programme

Morning Plenary talks

- *Experience Curves for Electricity Storage*
  Oliver Schmidt – Imperial College London
- *Experience Curves for Environmental Impact*
  Atse Louwen, Utrecht University
- *Experience Curves of Energy Efficiency and DSM*
  TEP Energy GmbH
- *Implementing experience curves in energy demand models and specific application in the ASTRA model*
  Tobias Fleiter & Stephanie Heitel, Fraunhofer ISI
- *(Title t.b.d.)*
  Uwe Remme, IEA - Energy Technology Perspectives
- More speakers to be announced

Afternoon Parallel discussion sessions

- Experience Curves: methodology and applications
- Implementation of Experience Curves in energy system models
- Experience Curves for future environmental impact assessment

Contact:

Dr. Atse Louwen
Utrecht University
Copernicus Institute for Sustainable Development

e-mail: a.louwen@uu.nl
Telephone: +31 30 253 7619
Web: www.reflex-project.eu/public

Figure 3: Invitation to workshop sent to the target groups

3. PARTICIPANT LIST

Table 1: Final attendees at the event

Name	Affiliation	Name	Affiliation
Alessia Elia	UC Cork	Katrin Seddig	KIT-IIP
Andreas Bublitz	KIT-IIP	Daniell Fett	KIT-IIP
Atse Louwen	UU	Felix Lill	CDTM
Carlos Blanco	Leiden University	Steffen Fattler	FGE München
Christoph Fraunholz	KIT-IIP		
Clas-Otto Wene	Chalmers University		
Dominik Möst	TU Dresden		
Hans Böhm	Energieinstitut an der JKU		
Jannik Haas	Uni. Stuttgart		
Laurent Vandepaer	USherbrooke/PSI		
Manuel Wetzel	DLR		
Martin Junginger	UU		
Maryegli Fuss	KIT-ITAS		
Natalya Tsoy	Leiden University		
Kristina Nienhaus	DLR		
Noah Kittner	UC Berkeley		
Oliver Schmidt	Imperial College London		
Peter Radgen	Uni. Stuttgart		
Pinar Korkmaz	Uni. Stuttgart		
Sabrina Ried	KIT		
Simonas Cerniauskas	Forschungszentrum Jülich		
Steffi Weyand	TU Darmstadt		
Stephanie Heitel	Fraunhofer ISI		
Sven Peterhammer	DLR		
Martin Jakob	TEP Energy		
Thomas Martinsen	NMBU		
Dr. Thomas Schlegl	Fraunhofer ISE		
Lei Xu	KIT-ITAS		
Steffi Schreiber	TU Dresden		
Ulrich Reiter	TEP Energy		

4. AGENDA

Plenary Sessions **Wednesday, 8th November 2017, 09:00 – 12:30** **Room: 418** **Chair: Dominik Möst**	
Time	Topic
08:45	Registration
09:00	**Welcome and introduction** General introduction of the REFLEX project (Dominik Möst, TUD) REFLEX WP3 Overview (Atse Louwen/Martin Junginger, UU)
09:20	**Experience Curves for Electricity Storage Technologies** Oliver Schmidt (Imperial College)
09:50	**Experience Curves for DSM technologies** Ulrich Reiter or Martin Jakob (TEP Energy)
10:20	**From learning curves for current technologies to new & emerging technologies** Uwe Remme (IEA)
10:50	Coffee Break
11:20	**Case study: application of experience curves in the ASTRA transport model** Stephanie Heitel (Fraunhofer ISI)
11:50	**Experience Curves for Assessment of Environmental Impact** Atse Louwen (Utrecht University)
12:15	**Quantum Modelling of the Learning Curve – Achievements and Prospects** Clas-Otto Wene (Wenergy)

12:30	Lunch break

Parallel Sessions **Wednesday, 8th November 2017, 13:30 – 16:20**			
Time	**Experience Curves Methodology** Chair: Martin Junginger (UU)	**Model Implementation** Chair: Steffi Schreiber (TUD), Tobias Fleiter (ISI)	**Environmental Impact** Chair: Atse Louwen (UU)
13:30	**One vs Two-factor Experience Curves** Noah Kittner (UC Berkeley) **Markets, spillover and radical innovations** Thomas Martinsen (NMBU)	**Implementing experience curves in an optimisation model - the example of ELTRAMOD** Steffi Schreiber (TUD) **Implementing experience curves in simulation models - examples from the buildings and industry sectors** Tobias Fleiter (Fraunhofer ISI) **Implementation of experience curves in a system dynamics model using the example of TE3** Katrin Seddig (KIT-IIP) **Implementation of Experience Curves in the Electricity Market Simulation Model PowerACE** Christoph Fraunholz (KIT-IIP)	**Experience Curves for Future Environmental Impact Assessment** Atse Louwen (UU) **Lifecycle Inventory Updating for Future Environmental Impact Assessment** Mary Fuss / Lei Xu (KIT-ITAS)
14:30	**Coffee break**		
14:45	**Discussion**	**Discussion**	**Discussion**
16:00	**Wrap up and closing (UU)**		
16:20	**End of workshop**		