Short characterisation of the *Green*-X model

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… developed initially in the period 2002 to 2004 within the research project
Green-X (5th framework programme of the European Commission, DG RESEARCH)

www.green-x.at

Energy Economics Group at TU Wien

- The Energy Economics Group (EEG) is within the Institute of Energy Systems and Electric Drives at Technische Universität Wien (TU WIEN). EEG's key research areas are:
  - Dissemination and integration strategies for renewable and new energy systems
  - Energy modelling, forecasting and analysis of energy policy strategies
  - Competition in energy markets (liberalisation vs. regulation)
  - Sustainable energy systems and climate change
- EEG, employing a permanent scientific staff of about thirty people with expertise across all disciplines necessary to assess the impact of energy policy initiatives at the European level, has managed and carried out many international and national research projects funded by the European Commission, national governments, public and private clients.

Energy Economics Group
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- EEG is at the forefront of discussion on energy policy instruments for the enhanced deployment of renewable energies at the European level as well as at global scale. It substantially contributed to the assessment of the effectiveness and efficiency of support schemes for renewable energies either by conducting ex-post or ex-ante evaluations.
- Consequently, to **facilitate prospective assessments** and scenario elaboration, **a broad set of in-door models** have been developed by EEG.
  - One of the most prominent tools in this respect is the Green-X model. This model allows performing a detailed quantitative assessment of the RES deployment until 2030 in a real-world policy context at national and European level. It has been successfully applied for the European Commission within several tenders and research projects to assess the feasibility of "20% RES by 2020" and for assessments of RES developments beyond that time horizon (up to 2050).

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1. Introduction: Objective

The core objective of the project *Green*-X was

to develop a computer model allowing an assessment of the future deployment of RES-E in the 'real world'.

Derived objectives are:

- to **describe the potential & the accompanying cost of the various RES-E options** in a brief and suitable manner for model implementation;
- to **model the impact of policy instruments**;
- to **address dynamic aspects in a proper way**, including:
  - Future **technological changes** – e.g. a reduction of investment costs or efficiency improvements due to technological learning
  - **Technology diffusion** – i.e. the impact of non-economic barriers for RES-E

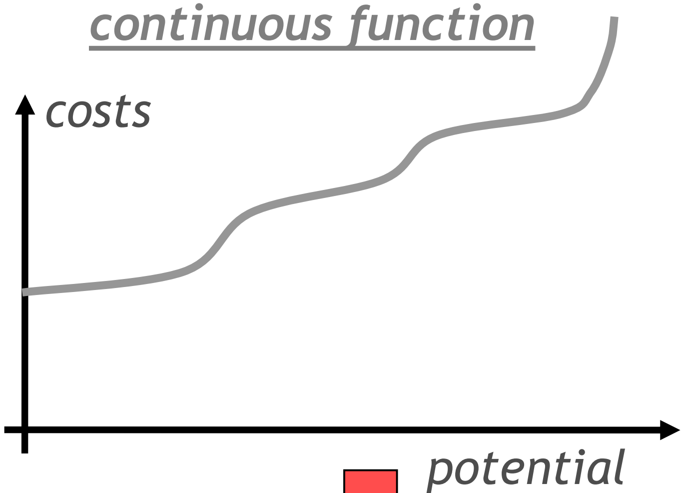
… to derive a picture of a likely future as close as possible to reality …

2. Basic principles: Static cost-resource curves

- Combines information on the ***potential*** and the according ***costs*** (of electricity/heat/fuel for a specific energy source).
- For ***limited resources*** (as RES-E) ***costs rise with increased utilization.***
- All costs/potentials-bands are ***sorted in a least cost way***

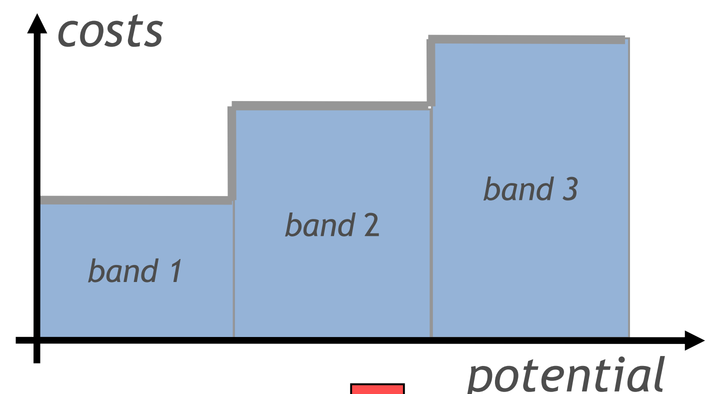
costs = f (potential); t = constant

continuous function



„…every location is slightly different"

stepped (discrete) function



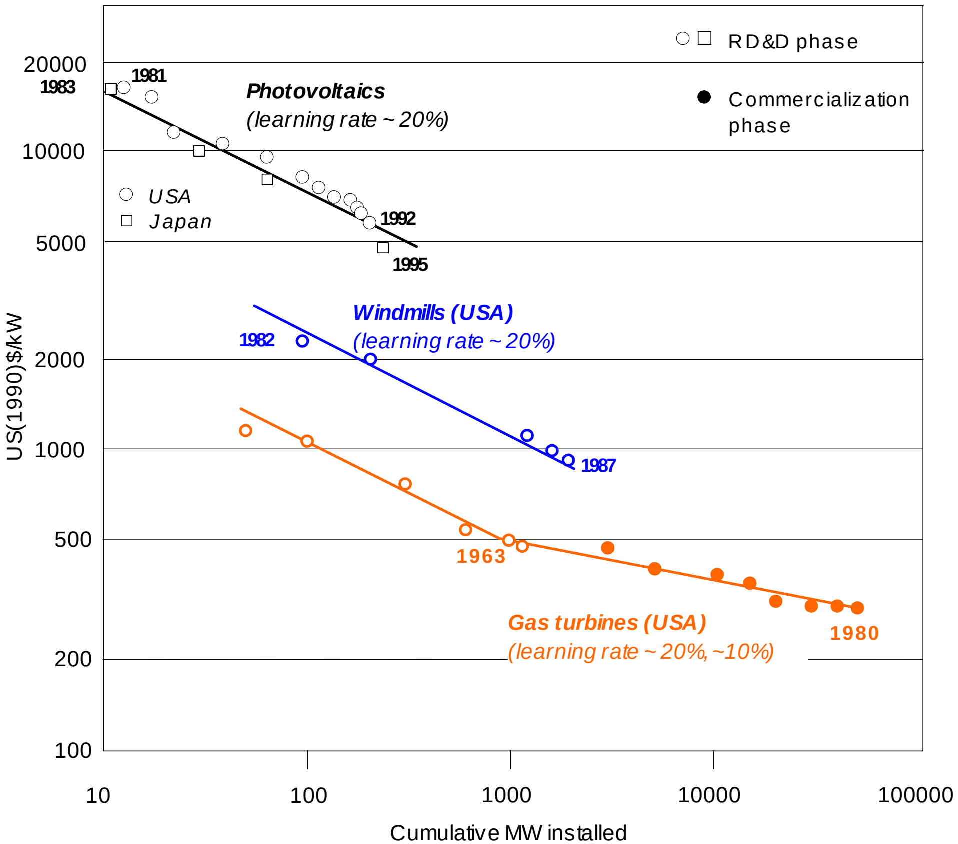
Practical approach: Sites with similar characteristics described by one band

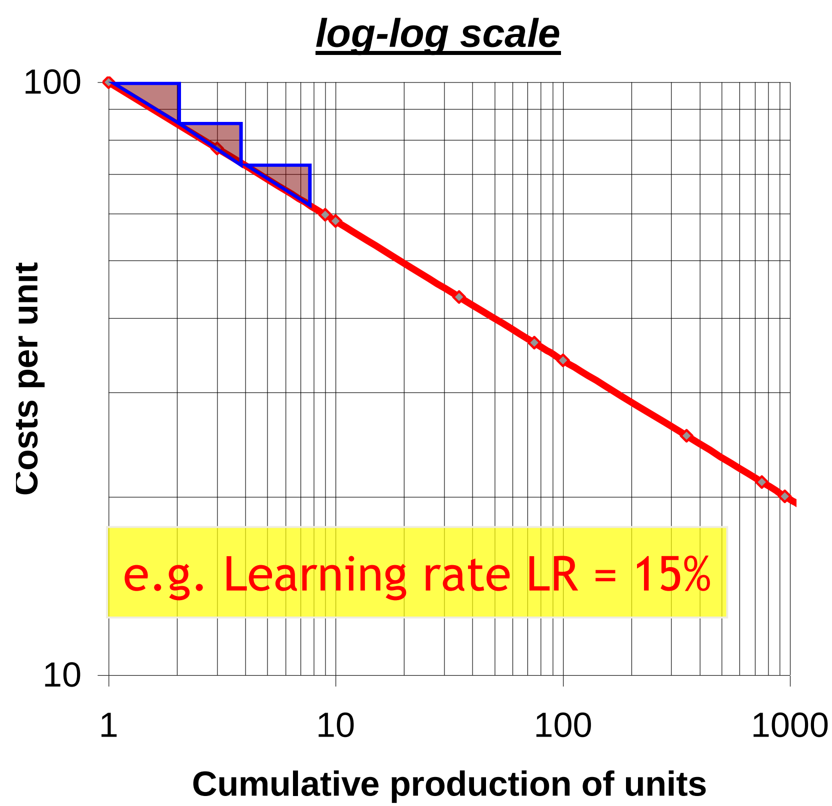
2. Basic principles: Experience curves

- describe ***how costs decline with cumulative production***.
- Empirical observations … costs decline by a ***constant percentage with each doubling*** of the units produced or applied.

$$C_{CUM} = C_0 * CUM^b$$

C_{CUM}	Costs per unit
C_0	Costs of the first unit
CUM	Cumulative production
b	Experience index
LR	Learning rate ($LR=1-2^b$)





2. Basic principles: Technology diffusion

General diffusion theory

$$F = \frac{1}{1+e^{-d*(t-t_0)}}$$

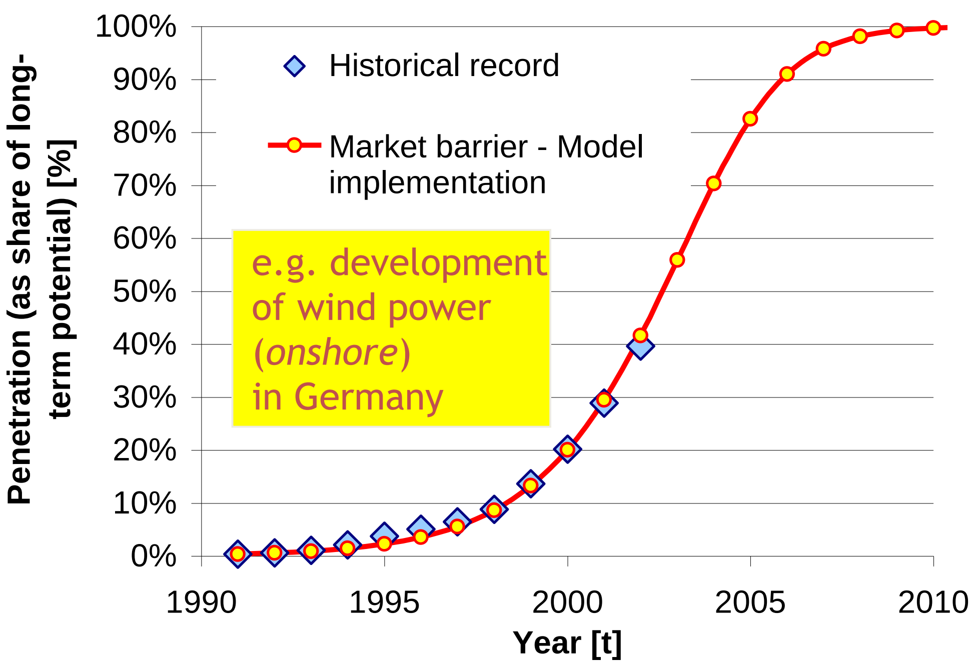
- ... in accordance with general diffusion theory, penetration of a market by any new commodity typically follows an **'S-curve' pattern**
- ... applied within the model to describe **the impact of non-economic barriers on RES-E deployment**

F	Markt penetration
d	Diffusion rate
ΔP_{Mn}	Yearly realisble potential (according to market barrier)
P	Long-term realisable potential

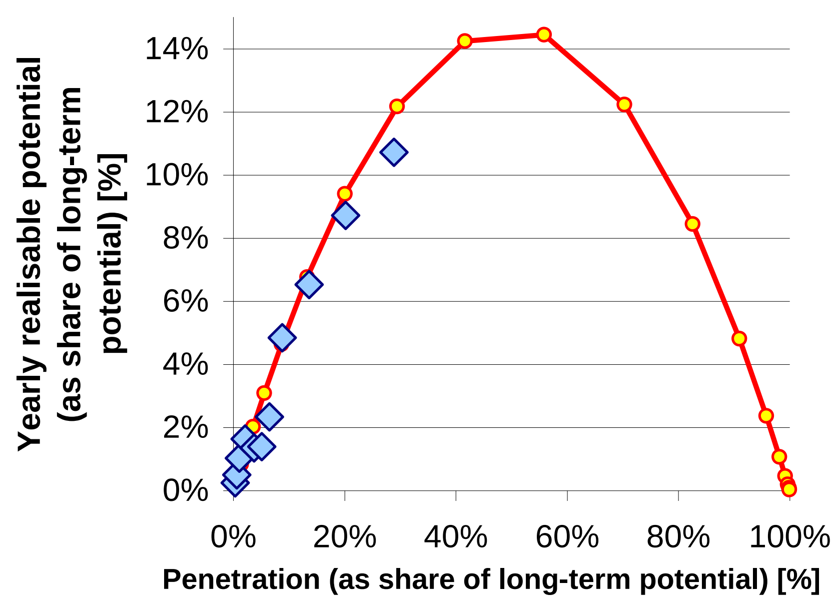
Model implementation of dynamic non-economic market barriers

$$\Delta P_{Mn} = P*d*F*(1-F)$$

Deployment



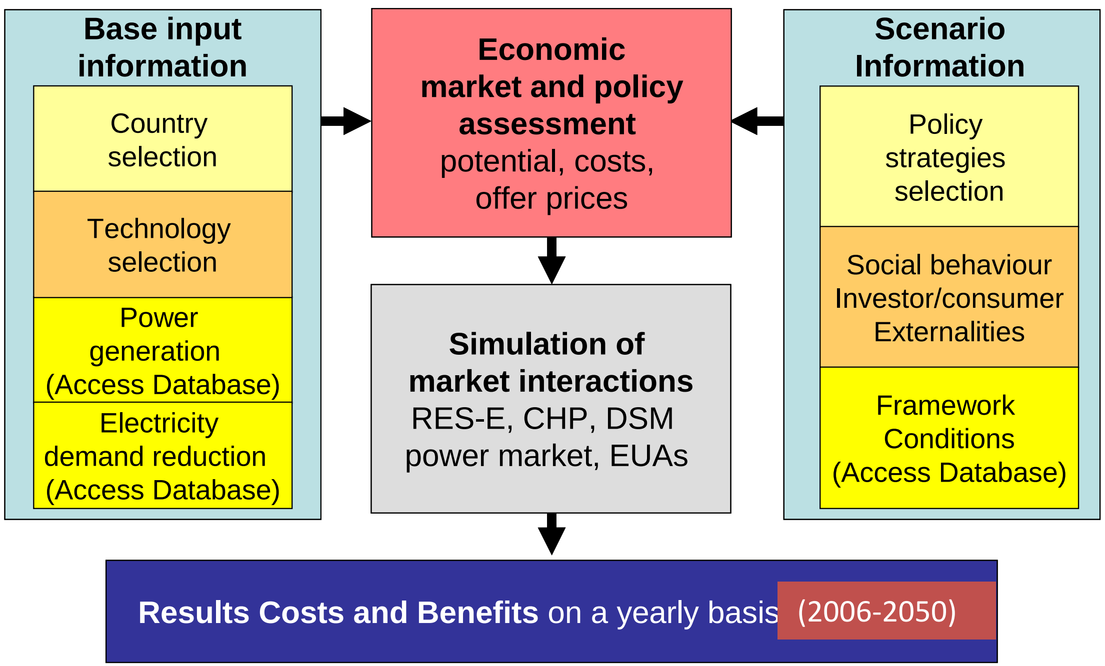
Realisable potential due to <u>non-economic Markt barriers</u>



The *Green-X* model

Simulation model for energy policy instruments in the European energy market

- RES-E, RES-H, RES-T and CHP, conventional power
- Based on the concept of dynamic cost-resource curves
- Allowing forecasts up to 2030(2050) on national / EU level



Reference clients: European Commission (DG RESEARCH, DG TREN, DG ENV, DG ENER), Sustainable Energy Ireland, German Ministry for Environment, European Environmental Agency, Consultation to Ministries in Serbia, Luxembourg, Morocco, etc.

A broad set of ***results*** *with respect to RES can be gained* ***on country and technology-level:***

► energy output by sector (RES-E, RES-H, RES-T), by country, by technology

► installed capacity & corresponding capital expenditures by sector, by country, by technology

► share on gross domestic electricity / heat / transport fuel demand

► (average) (additional) generation costs by sector, by country, by technology

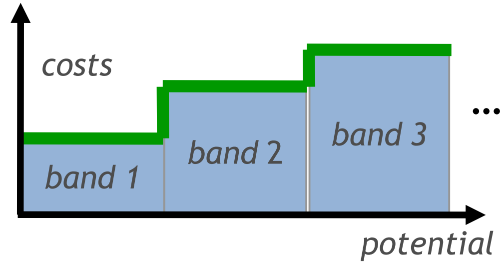
► avoided (fossil) primary energy and CO_2 emissions due to additional RES deployment by sector, by country, by technology

► impact of selected energy policy instruments on supply portfolio, costs & benefits to the society (consumer) – e.g. consumer expenditures due to RES support

(3) Green-X model - overview & approach

Mid-term (up to 2020)
realisable potentials in year n n+1

& corresponding costs for RES at country level by RES technology *(subdivided into several bands)*



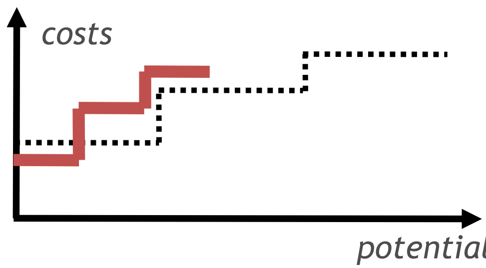
The *Green-X* approach:

Potential

Cost (efficiency)

Technology diffusion *('S-curve')*
(non-economic barriers by technology/country)

Technological change
((global) learning curves by technology)



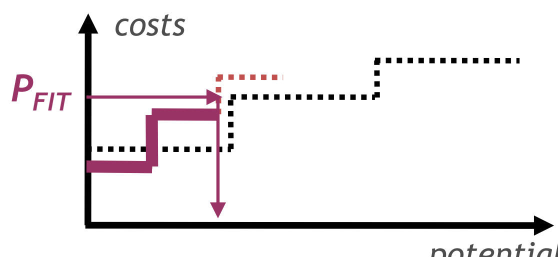
Dynamic cost-resource curves

Realisable yearly potentials in year n

&

Energy policy
(energy prices, RES support)

e.g. Feed-in tariffs,
Investment incentives,
Tendering schemes,
Quotas with tradable green certificates



a detailed energy policy representation

Deployment in year n

and corresponding costs & benefits

► Core Objective - *Method of approach* *for the policy assessment*

Support instruments have to be

- ***effective*** for **increasing the penetration of RES-E** and
- ***efficient*** with respect to **minimising the resulting *policy costs*** over time.

Policy costs or ***transfer cost for consumer / society*** (due to the promotion of RES-E) are defined as direct premium financial transfer costs from the consumer to the producer due to the RES-E policy compared to the case that consumers would purchase conventional electricity from the power market.

This means that these costs do not consider any indirect costs / benefits or externalities (environmental benefits, change of employment,

The *criteria used for the evaluation of various instruments* are based on :

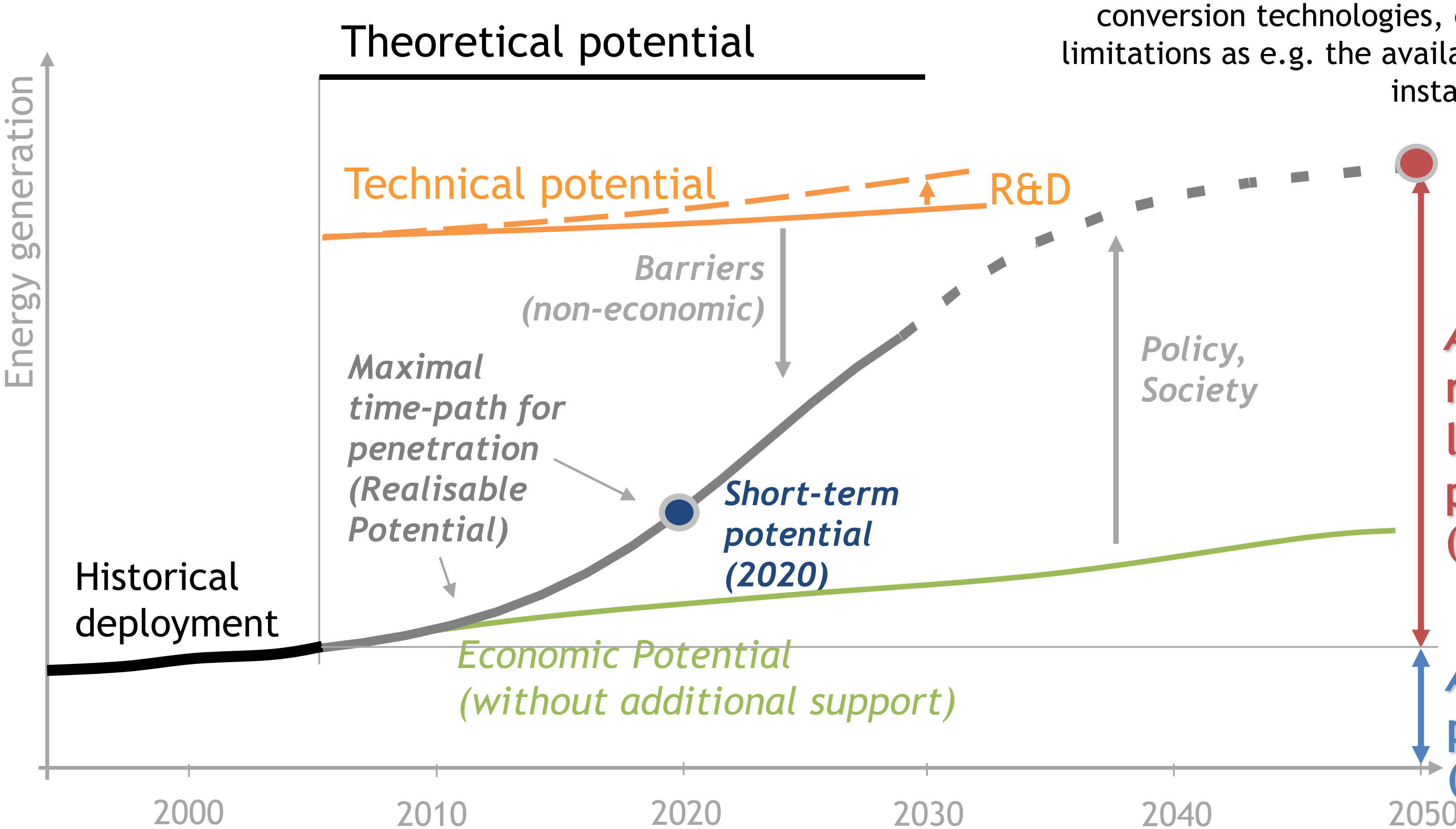
- ***Minimise generation costs***
- ***Lower producer profits***

Definition of the (additional) realisable mid-term potential (up to 2020/2030/2050)

Definition of potential terms

Theoretical potential ... based on the determination of the energy flow.

Technical potential … based on technical boundary conditions (i.e. efficiencies of conversion technologies, overall technical limitations as e.g. the available land area to install wind turbines)



▸ *Key assumptions*

To ensure maximum consistency with existing EU scenarios and projections the key input parameters of the Green-X scenarios are (as default) based on **PRIMES modelling** and the (updates of the) **Green-X database**.

Based on PRIMES*	***Defined for this study***
Energy demand by sector	RES policy framework
Primary energy prices	Reference electricity prices
Conventional supply portfolio and conversion efficiencies	RES cost (Green-X database, incl. biomass)
CO_2 intensity of sectors	RES potential (Green-X database)
	Biomass trade specification
	Technology diffusion
	Learning rates

Main input sources for scenario parameters

**Primes scenario used subsequently:*
Reference case (as of 2013)