Long-term Transition Paths towards a Sustainable Energy Supply

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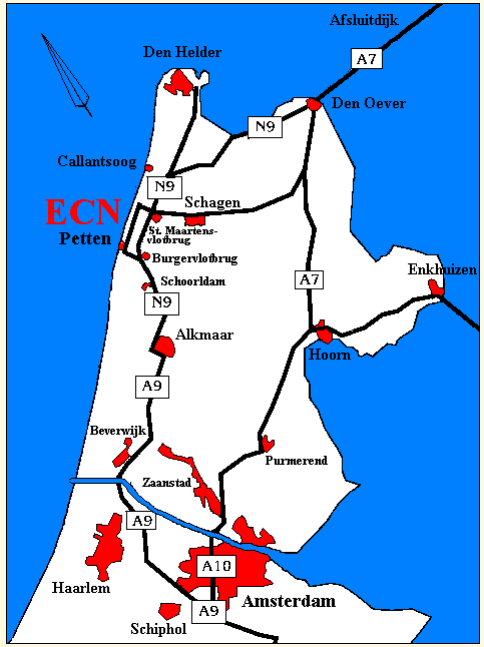
Four main parts of this presentation

- A short introduction to myself, ECN and the Transition and Innovation group
- “Transition”, a core concept in Dutch energy policy
- Modelling long-term transtions: example of the Western Europe electricity sector
- Innovation and learning: example of solar PV technology

Personal introduction

- Background in Physics and Sociology of Science and Technology (“Science and Technology Studies”)
- PhD. in 1998 on history of Fuel Cells and what can be learned from that for technology development mechanisms in general
- Renewable Energy policy specialist at ECN 1998-2001
- Manager of Transition and Innovation group since 2002

ECN, the Energy research Center of the Netherlands



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ECN, some characteristics

- Working force: 900 people
- Departments (units): 9
  - Solar, Wind, Biomass, Fuel Cells, Clean Fossil Fuels, Energy Efficiency in the Industry, Nuclear, Renewable Buildings and….. Policy Studies
- Mission: Contribute to transition to sustainable energy system by research
- Clients: governments (national and European), (large) enterprises

Policy Studies Unit

- Supports Dutch Government (Ministry of Economics) for contents recurring energy policy documents
- Takes part in many EU-funded policy projects
- Provides services to multi-lateral organisations + private sector

Policy Studies: 4 themes

- Climate Change Studies
  - emission trading, CDM, JI etc.
- Gas and Electricity Market studies
  - market modelling, studying different market designs (etc.)
- New and Renewable Energy Policy
  - RPS, Feed-In, potential and cost of renewable energy technologies
- Transition and Innovation Group
  - Long-term energy modelling, societal aspects of technological change

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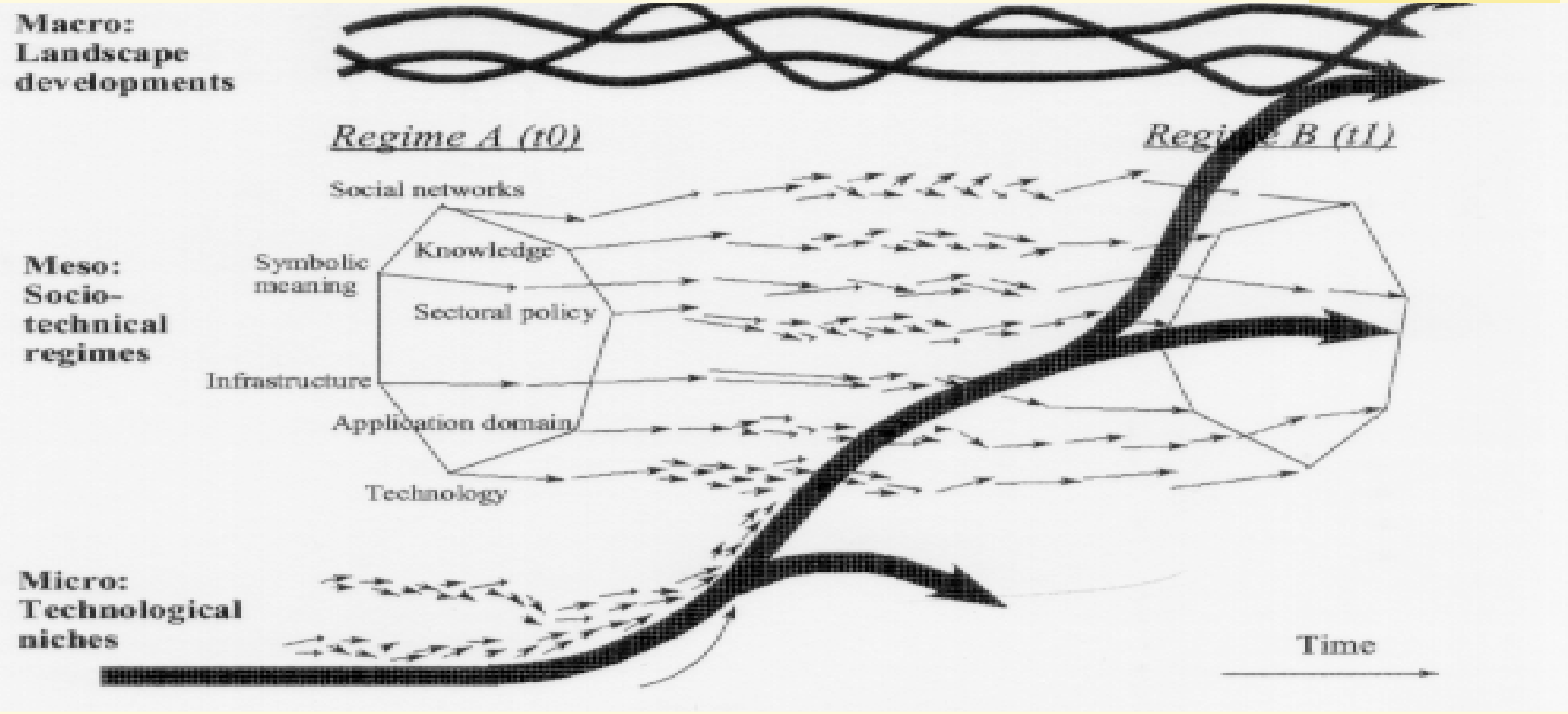
The concept of transition



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Characteristics of ‘transitions’

- Multi-level
  - novelties (in niches), regime en landschap
  - transition policy should be focussing on each of the three levels
- Multi-dimension
  - apart from technology also social networds, knowledge, user preferences, cultural meaning, sectoral policy and infrastructure
- Multi-actor
  - means that not everybody of today will join in forming the world of tomorrow
  - new connections and networks between actors will have to be constructed
- Multi-phase
  - RDD&D instead of R&D
  - one technology can ‘pave the road’ for another (see bikes and cars)

Transition management?

- What does ‘managing’ mean when you talk about such complex, long-term processes?
- Characteristics transition management
  - Long-term assessment part of shorter term decisions
  - Action/policy should be integral, I.e. focused on several domains, levels, actors
  - The concept of ‘learning’ is very important. How to improve learning is crucial
- Steps
  - Achieve some convergence on the transition target
  - Assess different ‘pictures of the future’ related to the target
  - Formulate intermediate targets and transition paths
  - Start and plan evaluation and learning cycles
  - Create societal support

Transition in Dutch policy

- Core concept in 4th National Environmental Report (2001)
- Focused on (Sustainable) Agriculture, Biodiversity, Mobility and Energy
- Ministry of Energy leads Energy Transition Policy
- Four 'transition trajectories' have been chosen: New gas (hydrogen?), biomass, regional energy systems and the energy-intensive industry
  - Lots of workshops
  - Start of drafting visions
  - thinking about transition paths
  - dealing with uncertainties by defining transition experiments

The role of the T&I-group in this discussion

- Bring knowledge on the concept of transition to our energy acquaintances
- Bring knowledge on energy technologies, economics and sector to our transition acquaintances
- Competences (10 people):
  - long-term energy modelling (MARKAL)
  - sociology of technology
  - energy economics

Transition in a broader European perspective

- Long-term forecasts and studies in several countries of the EU
  - (e.g. Germany, Finland, Denmark, UK)
- Strategic discussions on energy going on in several countries
  - France, Germany, Belgium, UK
- EU Energy policy directives
  - Renewable electricity targets
  - Alternative Fuels communication (23 % in 2020)
  - High level hydrogen working group

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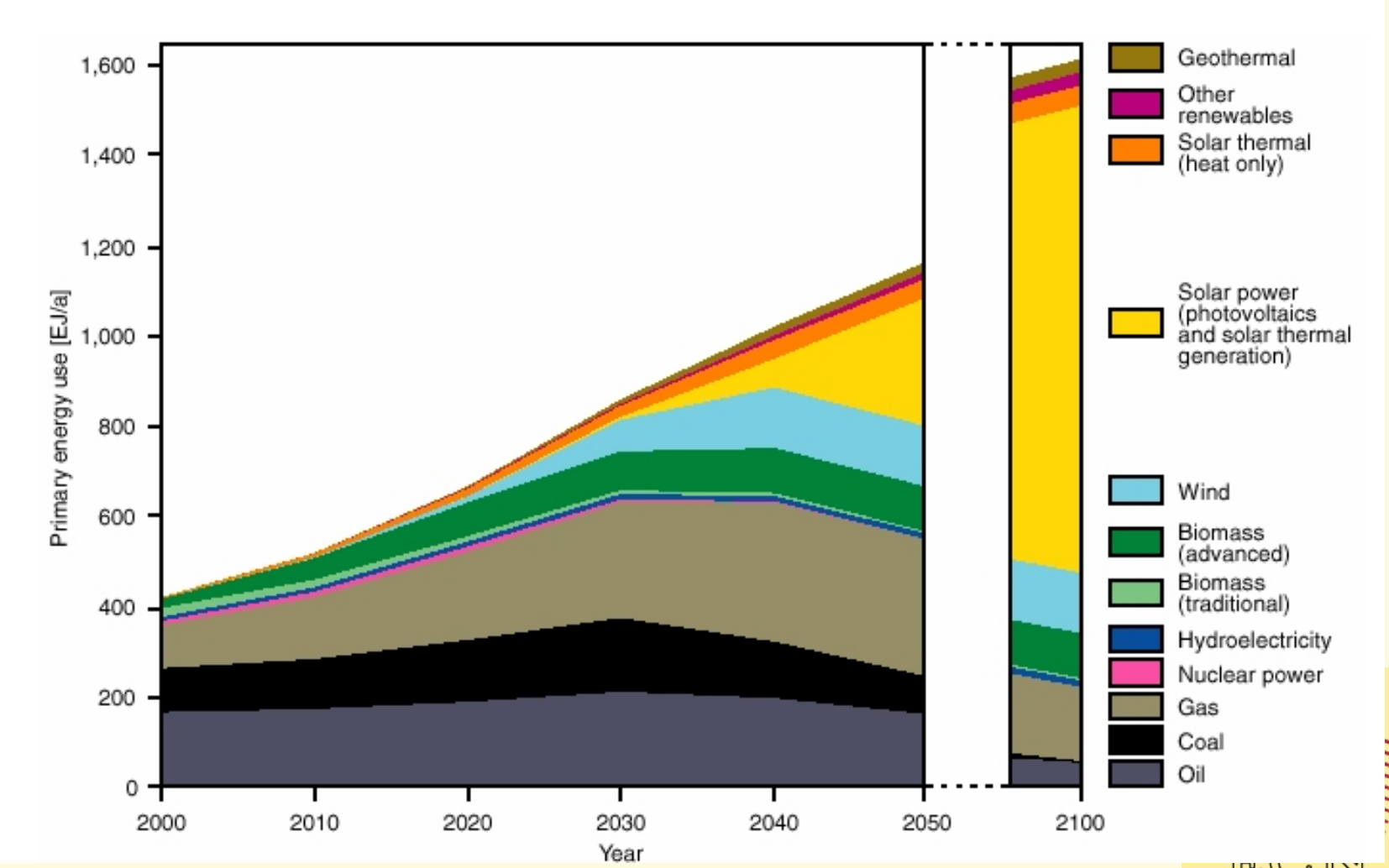
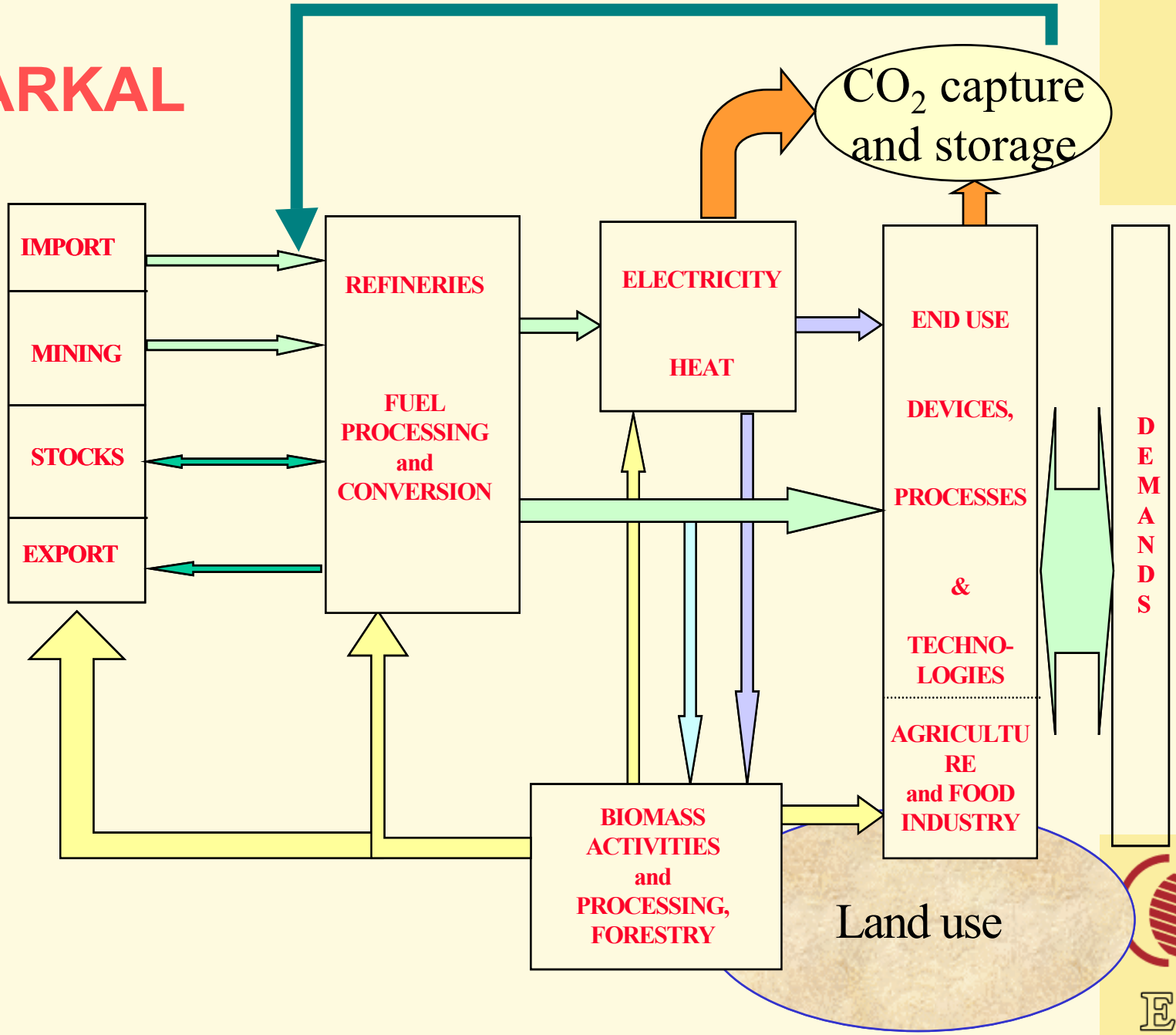
Germany's global energy transformation



MARKAL Western Europe (start of part 3)

- Single region region model covering OECD 1990 Western Europe
- Time period: 1990-2100 in 10 year steps
- Price elastic demand version: impact on end use demand under “severe” constraints
- Energy system with biomass-food industry sector included
- Endogenous technology learning (ETL) using SFLC (learning-by doing) and cluster approach (**This is a unique feature for large-scale models**)

MARKAL


CO_2 capture and storage
IMPORT
MINING
STOCKS
EXPORT
REFINERIES
FUEL PROCESSING and CONVERSION
ELECTRICITY
HEAT
END USE
DEVICES,
PROCESSES
&
TECHNO-LOGIES
AGRICULTURE and FOOD INDUSTRY
DEMANDS
BIOMASS ACTIVITIES and PROCESSING, FORESTRY
Land use

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Technological change

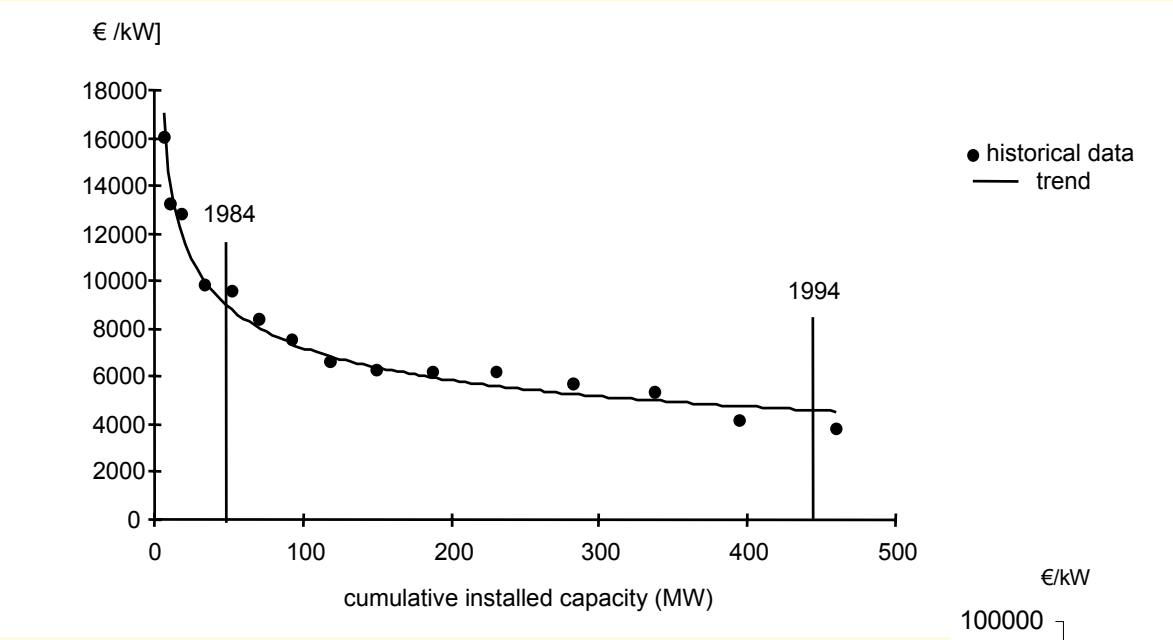
- Before 1999: technological progress induced through exogenous cost decrease

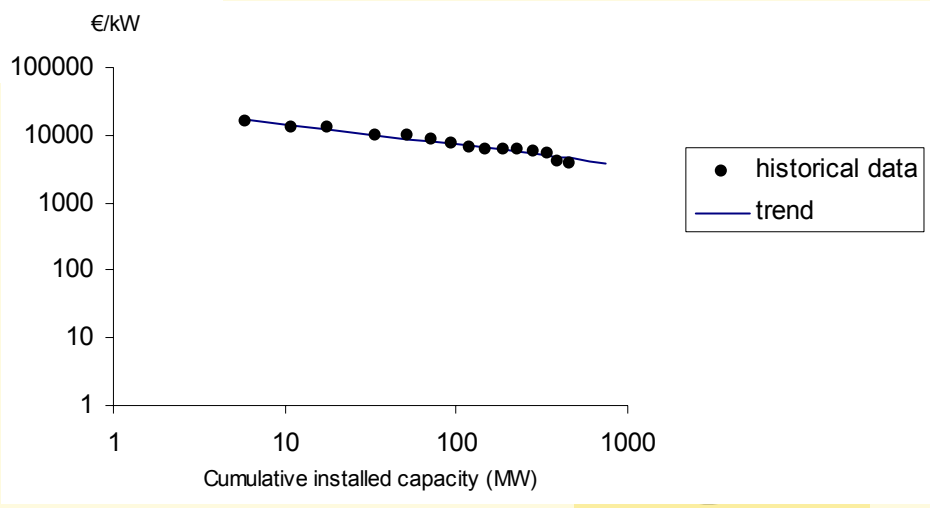
- 1999: learning-by-doing
  - investment costs decrease as function of cumulative capacity
  - learning curve: $SC(C) = a \cdot C^{-b}$
  - progress ratio ($pr = 2^{-b}$): cost reduction factor for each doubling in cumulative capacity

- 2001: learning-by-searching
  - investment costs also decrease as function of (public) R&D
  - component and cluster approach (learning)

Learning curves in MARKAL

Example: Solar PV modules (pr = 0.81)





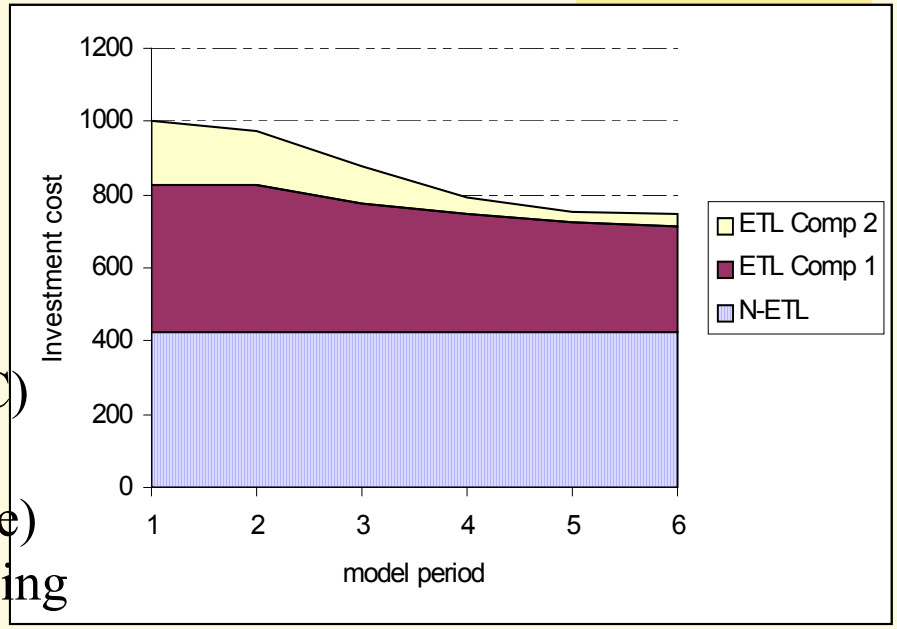
Clusters of technologies (1)

Definitions

- Cluster
  = a group of technologies sharing a common essential (i.e. learning) component; therefore the learning behaviour of these technologies is linked
- Component
  = the selected learning key technology shared by all technologies in a cluster
- Technologies are build by a number of components and a balance of system (infrastructure, non learning parts)

Clusters of technologies (2)

Parts of investment costs over time



Two examples of key technologies

Gas turbine

- many applications, simple cycle (SC) or combined cycle (CC)
- CC on gas, coal or biomass (see note)
- learning gas CC dominated by learning gas turbine

Note: coal and biomass CC (i.e. after gasification) = another cluster

Solar PV <u>module</u>

- many markets, regional differences
- PV system = PV module (shared) + BOS (customized)

Clusters of technologies (3)

19 clusters currently implemented

Cluster no.	*Description*	*# technologies in cluster*
1	Solar PV modules	6
2	Wind turbine	8
3	Fuel cell	13
4	Hydro turbine	4
5	Gas turbine	32
6	Gasifier	20
7	Steam turbine	45
8	Boiler	14
9	Combined cycle boiler	25
10	Nuclear reactor	1
11-15	CO_2 sequestration	10
16-18	Up stream oil and gas	15
19	Fusion reactor	2

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Multi Sectoral Learning - Clusters

- Learning components-clusters in:
  - up stream oil and gas exploitation (3)
  - electricity production (13)
  - CO_2 capture (3)

- more than 90 technologies with 1 or more learning components:
  - up stream oil and gas exploitation (9)
  - electricity production (69) & transport (fuel cell; 7)
  - CO_2 capture (9)

Long-term transitions runs for electricity sector

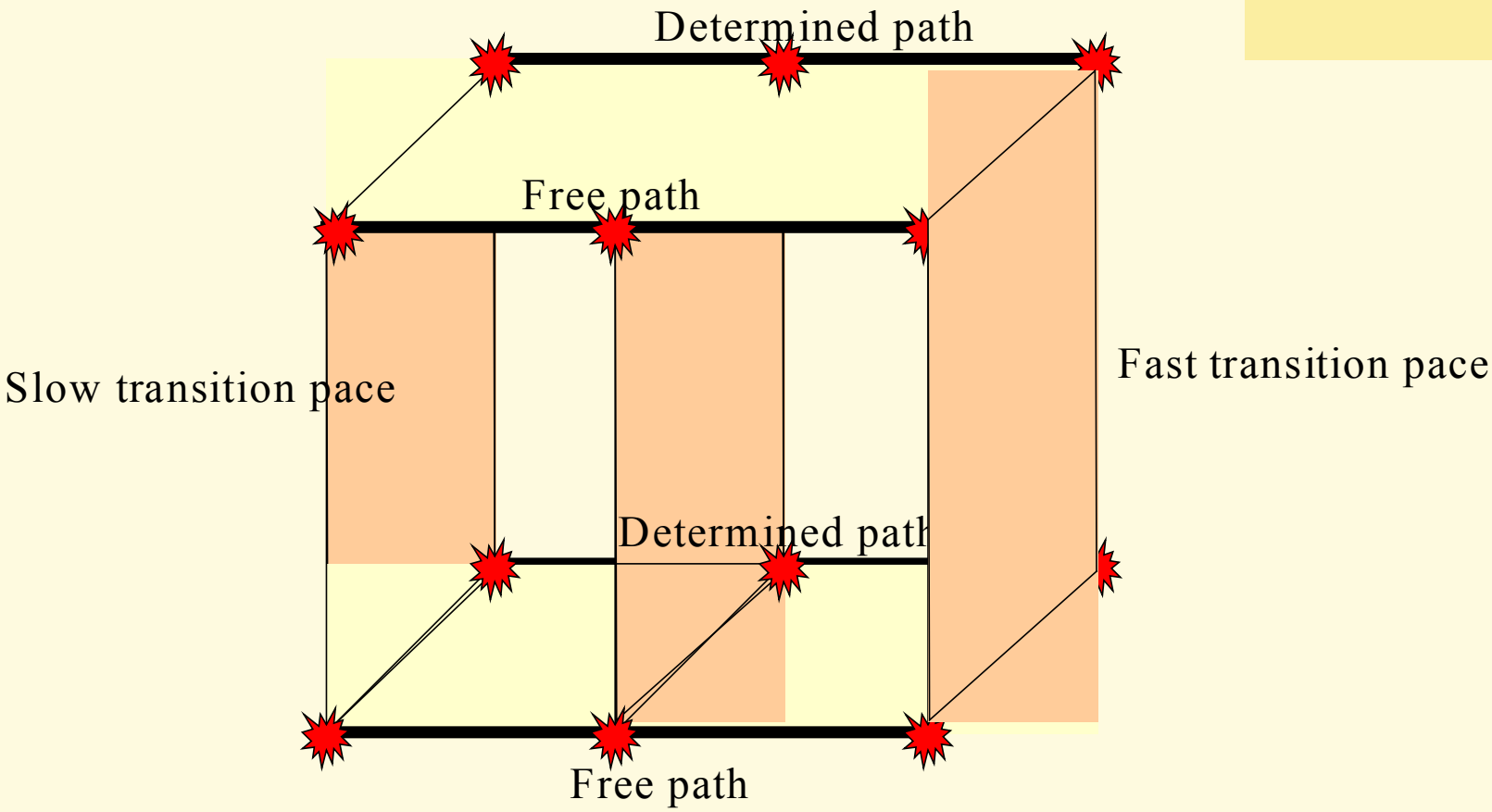
- Purpose: to test radical future images in a long term technology rich model

- Renewable electricity (green) target:
  - 100% by 2050, 2070 and 2100
  - optimal path and linear fixed path from 26% in 2010

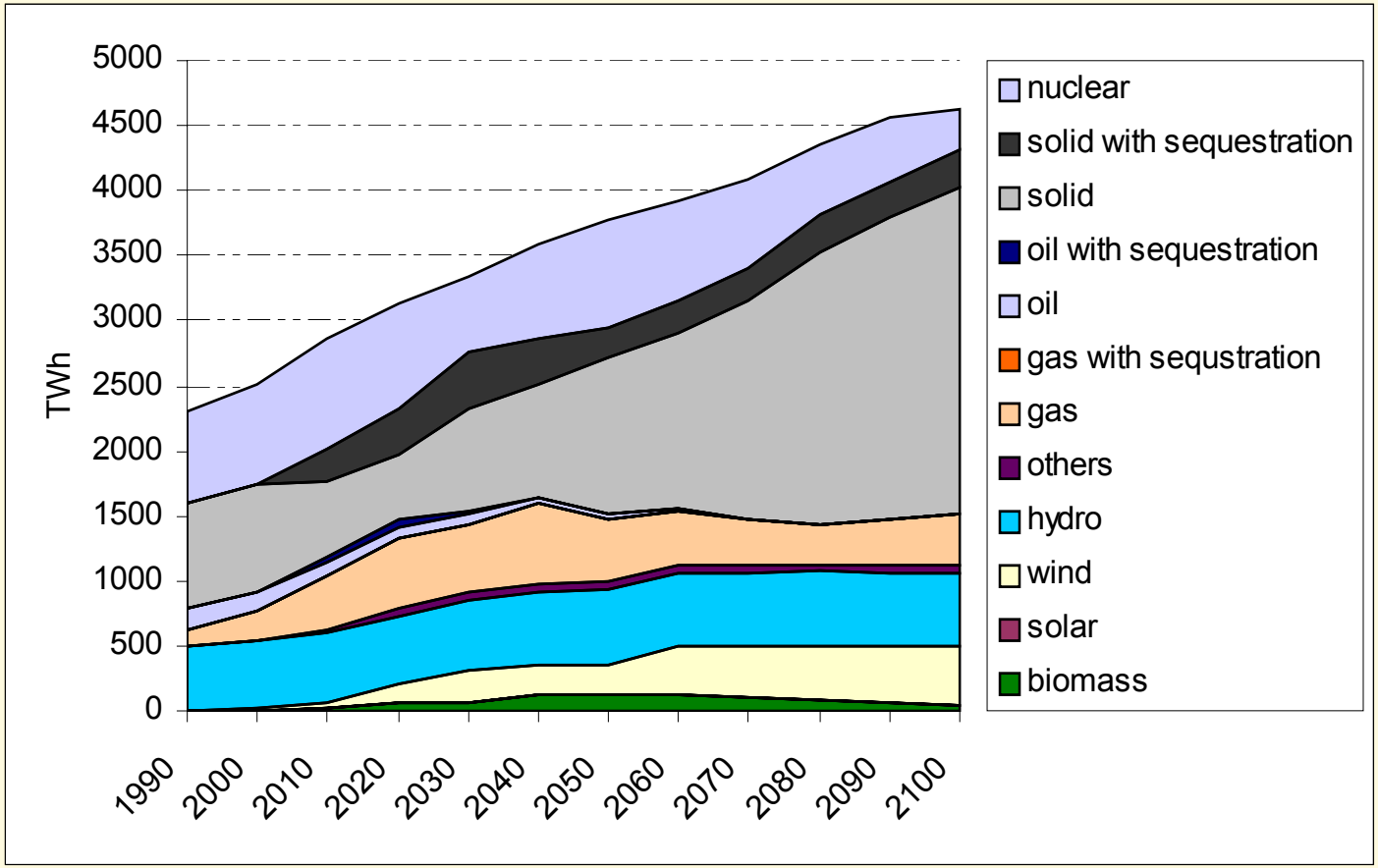
- CO_2 less electricity production:
  - 0 Mton CO_2 in 2050, 2070 and 2100
  - optimal path and fixed linear path from 850 Mton in 2010

- No new investments in fission (LWR) reactors after 2000

Scenarios


Determined path
Free path
Slow transition pace
Fast transition pace
Determined path
Free path

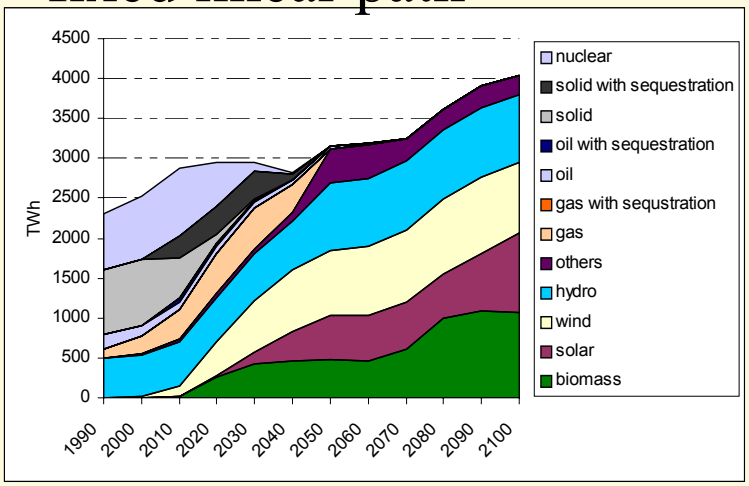
Base case: electricity production



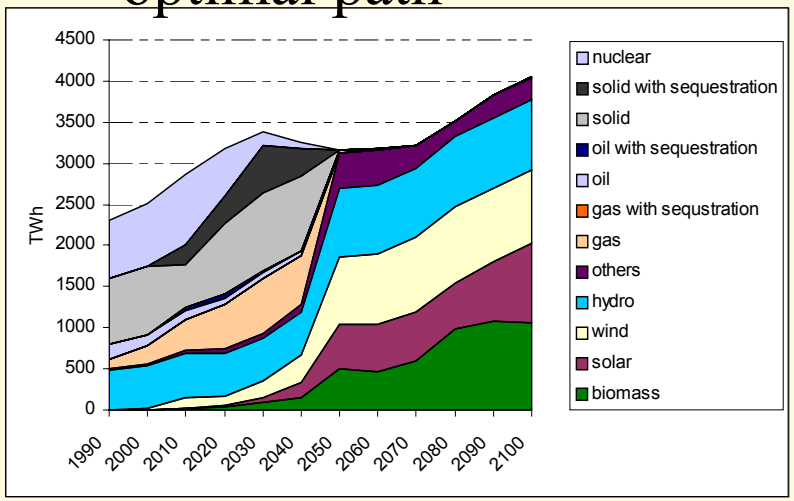
	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Share renewable electricity	19.9%	19.4%	18.8%	21.7%	23.5%	22.7%	21.7%	24.3%	23.4%	21.8%	20.8%	25.8%

Scenario results

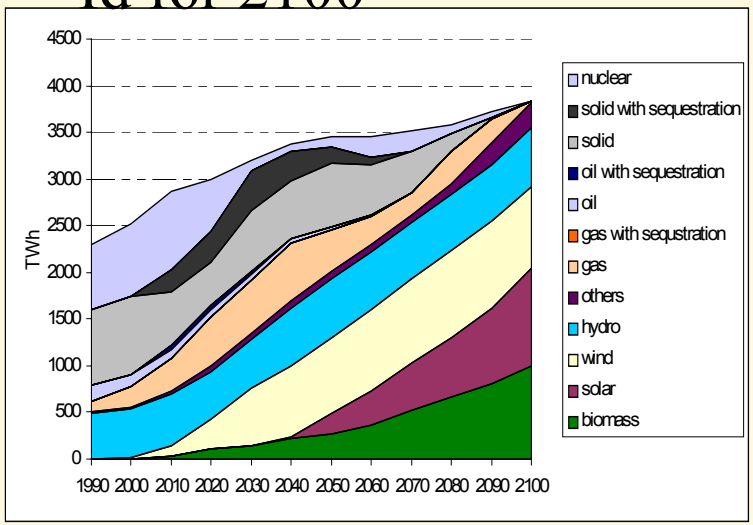
100% renewable by 2050, fixed linear path

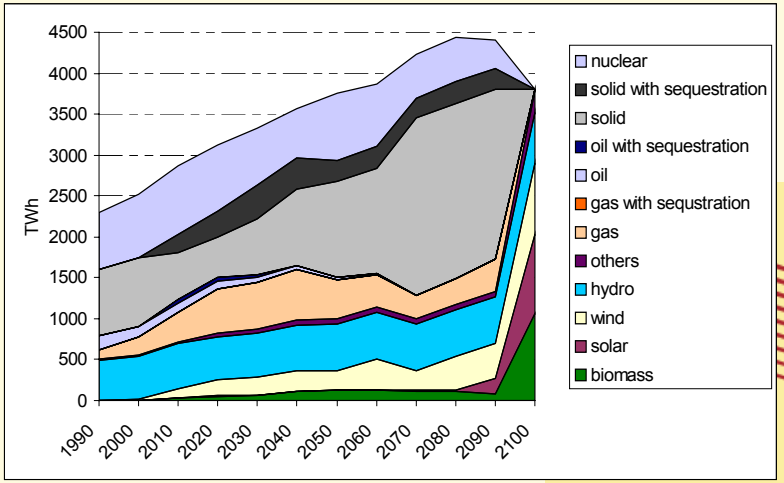


optimal path



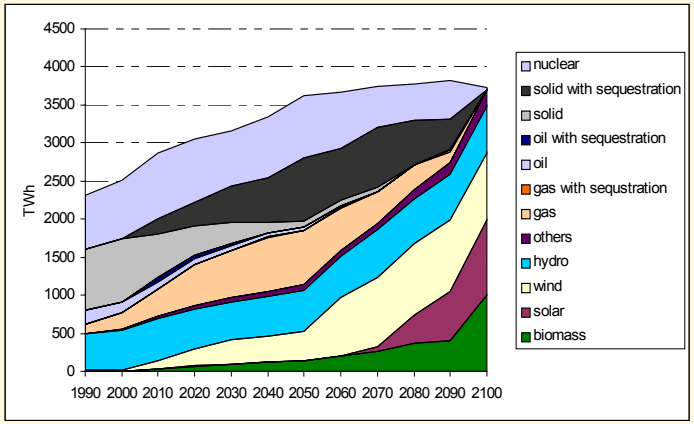
Id for 2100

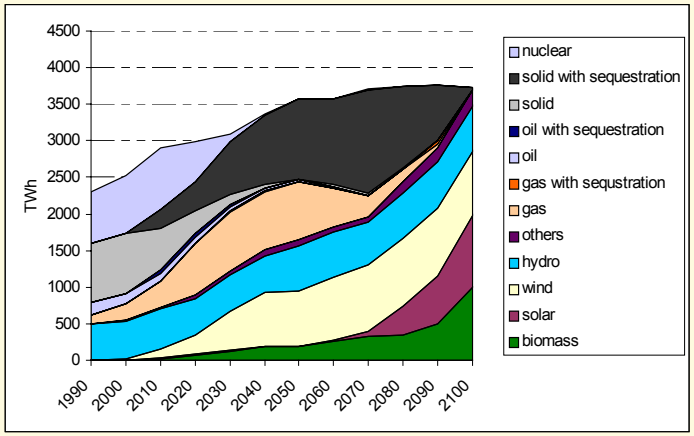




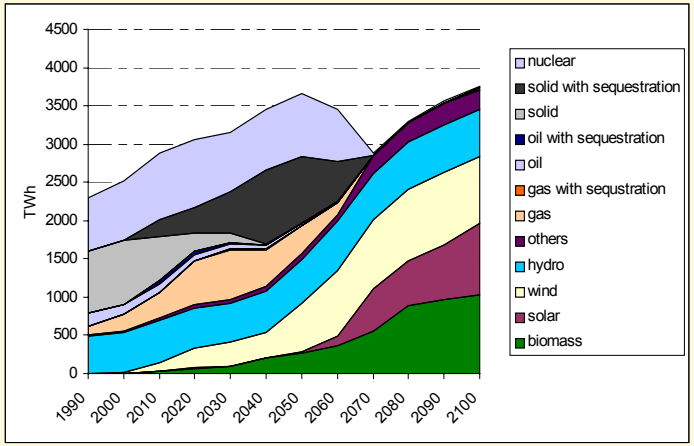
Scenario results

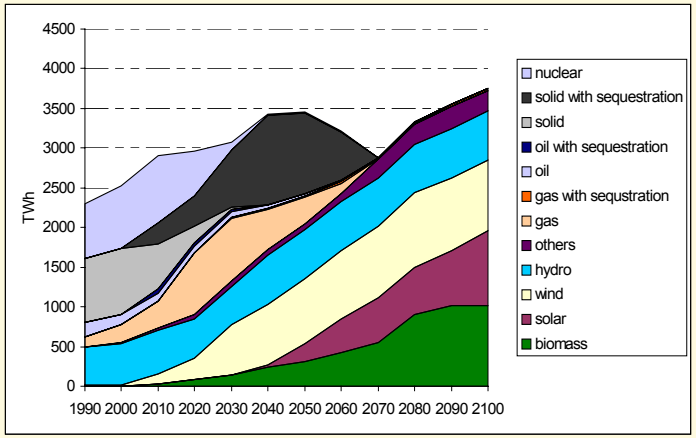
0 CO_2 and 100% renewable, with (left) and without nuclear (right)





2100

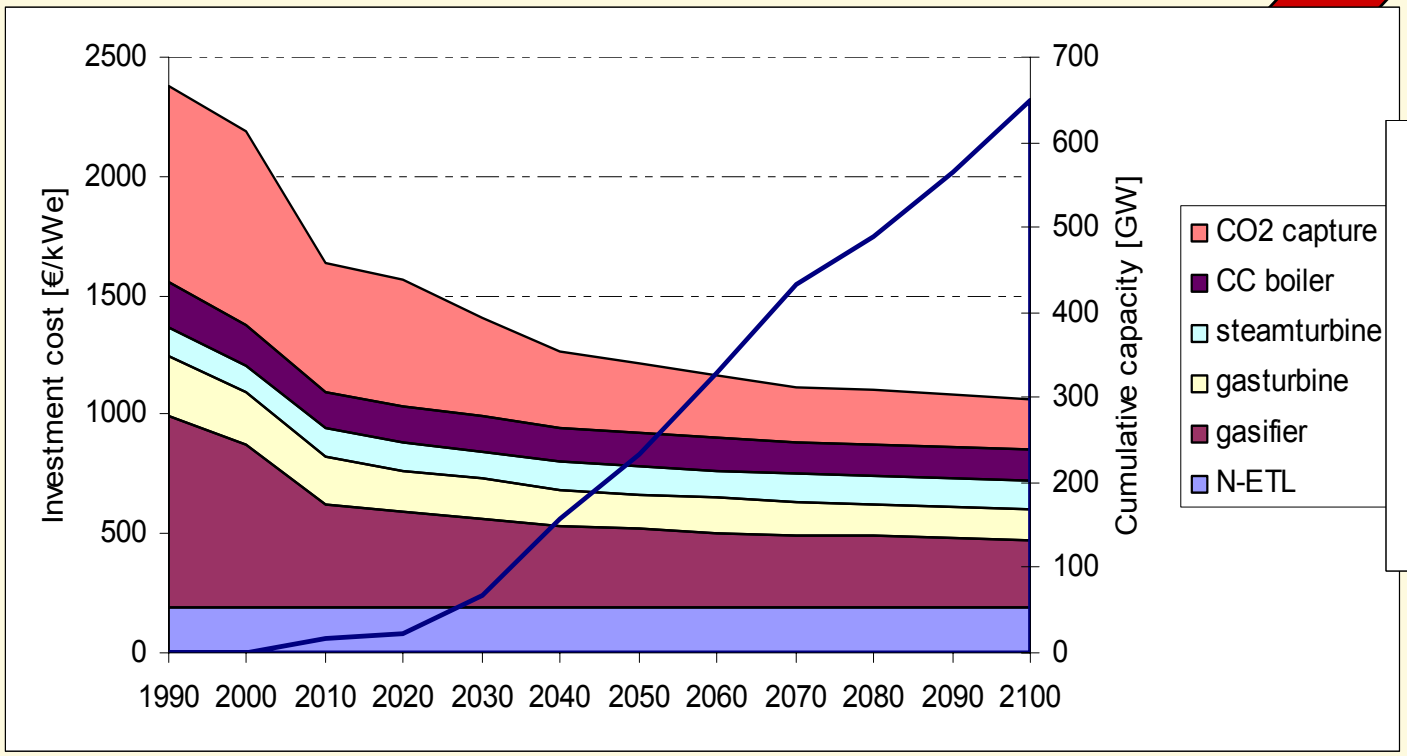


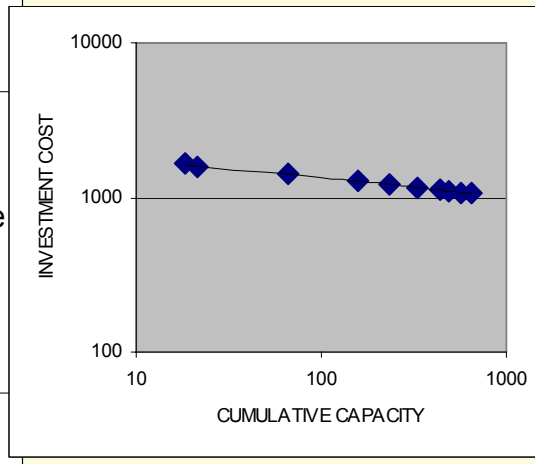


2070

Results: Learning Effects - Clusters

E.g. IGCC with flue gas CO_2 capture

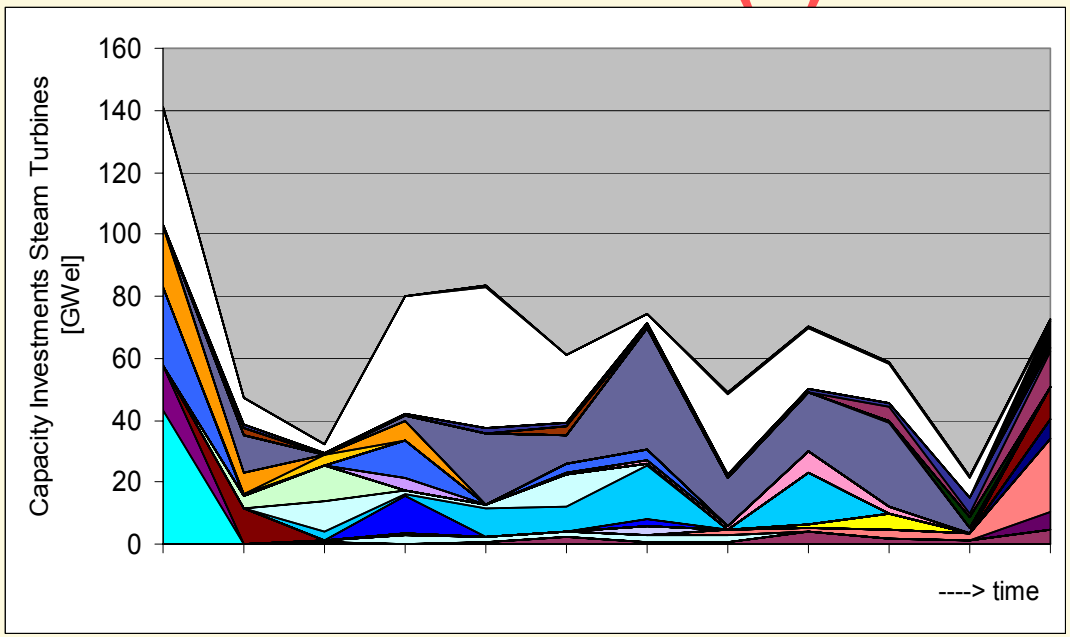


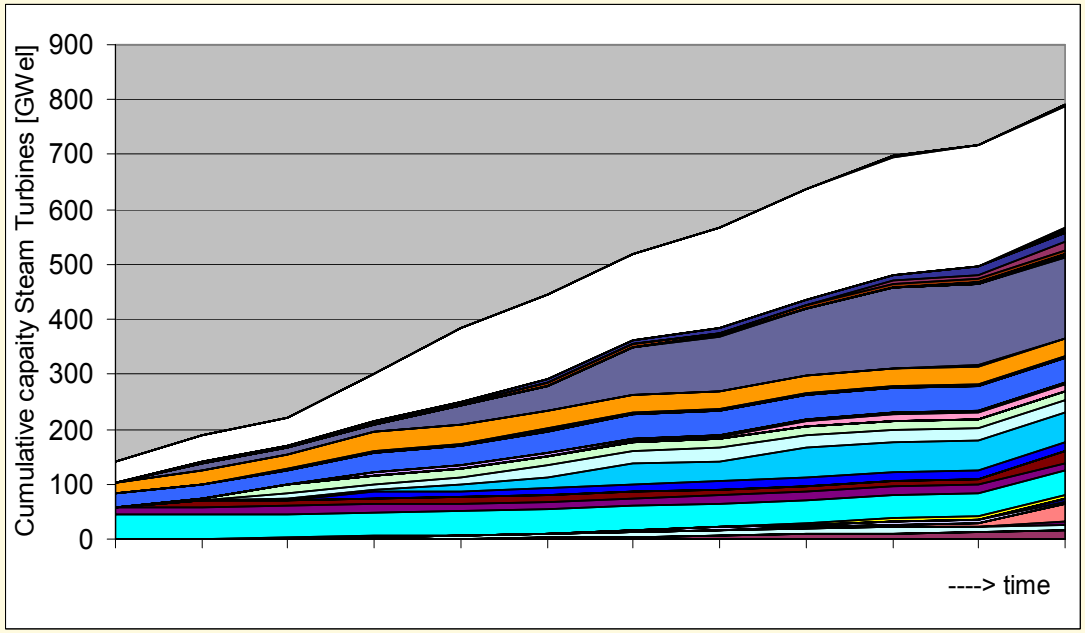


=> PR = 0.907

Clusters lead to technology spill-over and shared learning experience

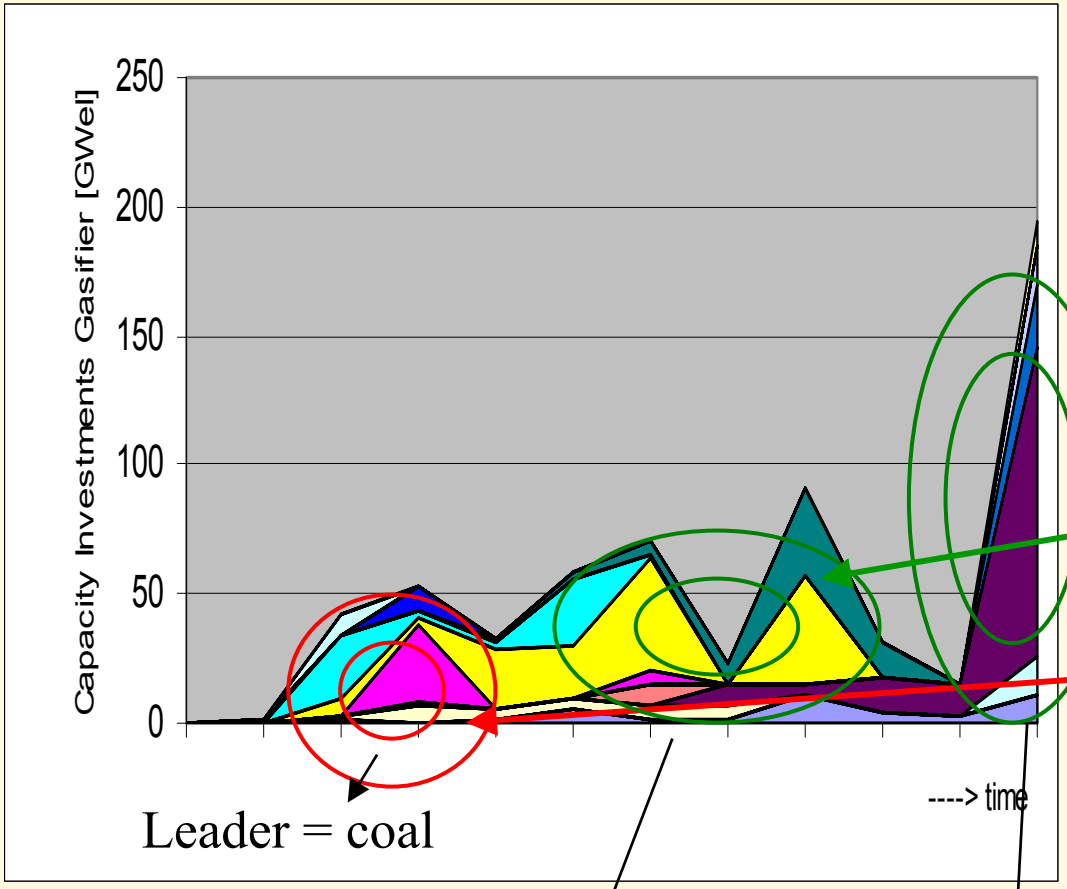
Results: Learning Effects - Clusters (2)





- Mature technology example: steam turbine
- Capacity investments per technolog in a cluster indicates relative contribution to learning experience
- Cumulative capacity of component is equally built up by contributions from all technologies in the cluster

Results: Learning Effects - Clusters (3)



Leader = coal

Intermediate follower = coal with CO_2 capture and SOFC

Last follower = biomass

- Promising technology example: gasifier
- Capacity investments per technolog in a cluster indicate which technolog is leader and which is follower

⇒preferential areas/technologies for (policy) intervention

Results: comments

- All scenarios show a dip in electricity production in the target year:
  - system (model) postpones efforts to the end
  - effect most moderate for 2100
- System (model) uses fossil or non renewables as much as possible in the free path scenarios => even with perfect foresight still some inertia to reach severe targets; all changes occur in 10-20 years before target year.
- Emission free scenarios not only achieved by renewables, also nuclear and CO_2 sequestration play a role.
- Emission reductions in electricity sector partially (20% on average) annulled by increased CO_2 emissions in other sectors (price electricity ↗ so more competition with other energy carriers (fossils) in end use).

Results comments (2)

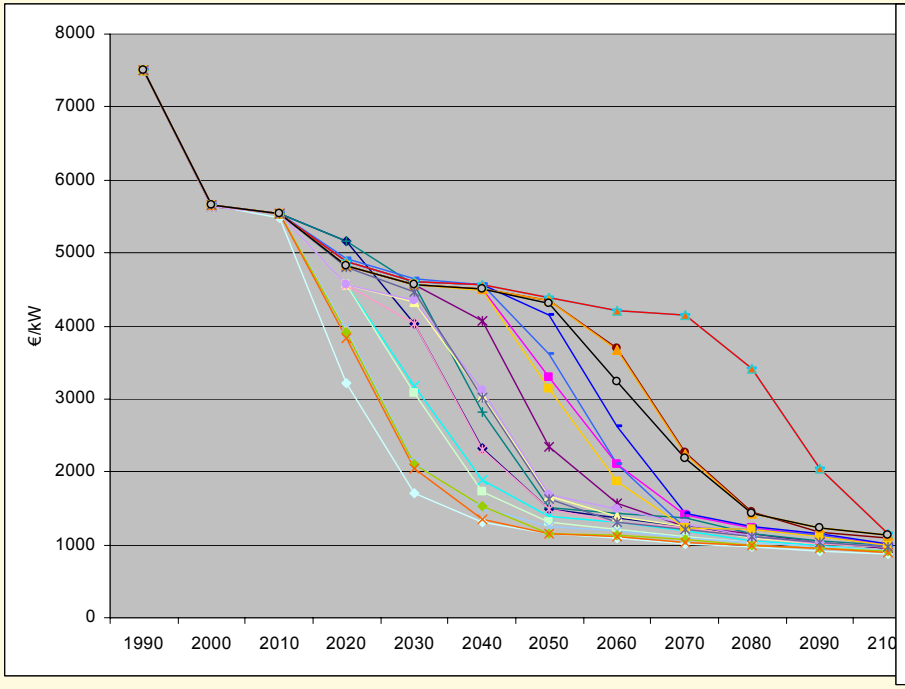
- Costs analysis is complicated by use of price elastic model version: system cost for some reduction scenarios becomes cheaper than base case, but loss of welfare is significant.
- Electricity costs see peak in target year, for free and determined scenarios, afterwards more relaxed, so cheaper.
- Welfare loss over whole period is about 0.05 to 0.30 % of total GDP (28500 trillion €).
- Nuclear phase out also investigated => targets can also be reached without new nuclear but electricity costs increase with 6% on average.

Results: comments (3)

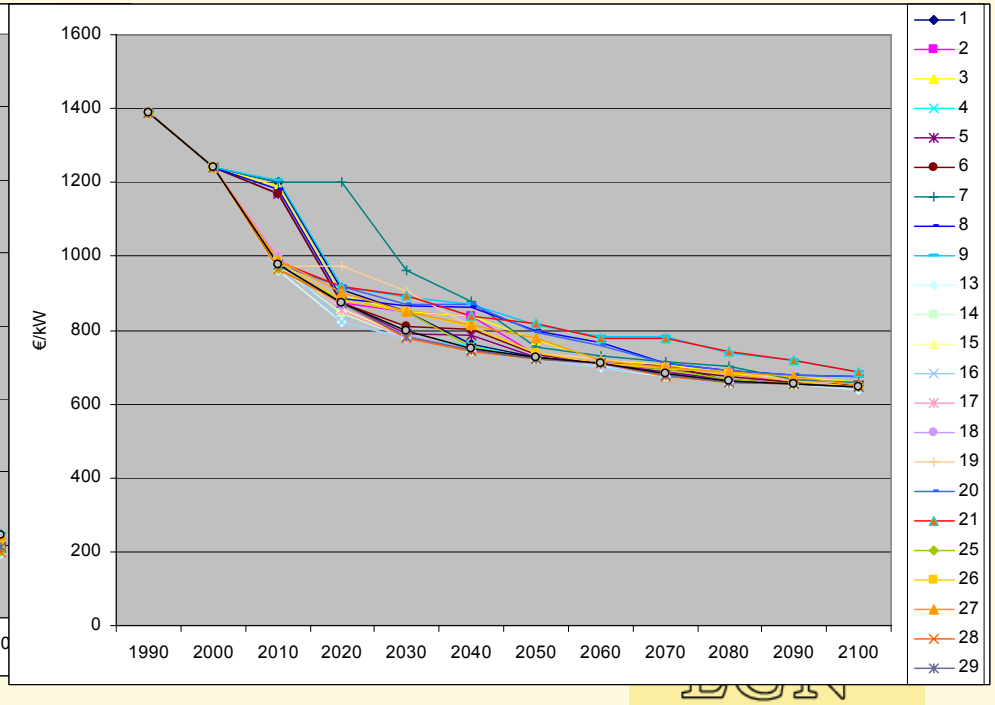
- Technology learning is very much scenario and scenario assumptions dependent (e.g. discount rate or fuel prices) as well as from the learning curve parameters (e.g progress ratio)

Specific Investment Costs [€90/kWel]

Solar PV



Wind turbines



Conclusions modelling part

- MARKAL as technology-rich model is extremely suitable to include learning (by doing). Not only new, promising technologies but also mature technologies balance the scenario results. The cluster approach offers wider areas for analysis and allows technology transfer and spill-over (between sectors and regions).

- The first model runs looking at transition scenarios are promising. Single year targets give rather unlikely results and path or intermediate targets lead to more acceptable and realisable changes in the energy system.

- Further elaboration of transition items (regimes, niche markets, ..) and future images (policy targets) in the model will increase its relevance and applicability

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In search of the right balance between market deployment stimulation and R&D

The case of Solar PV

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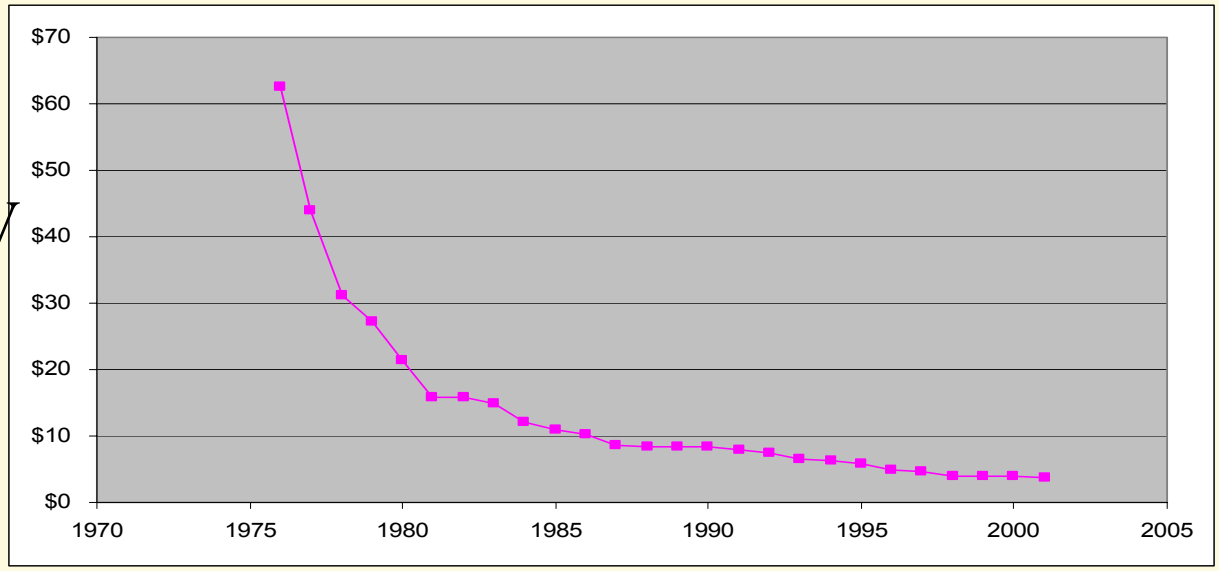
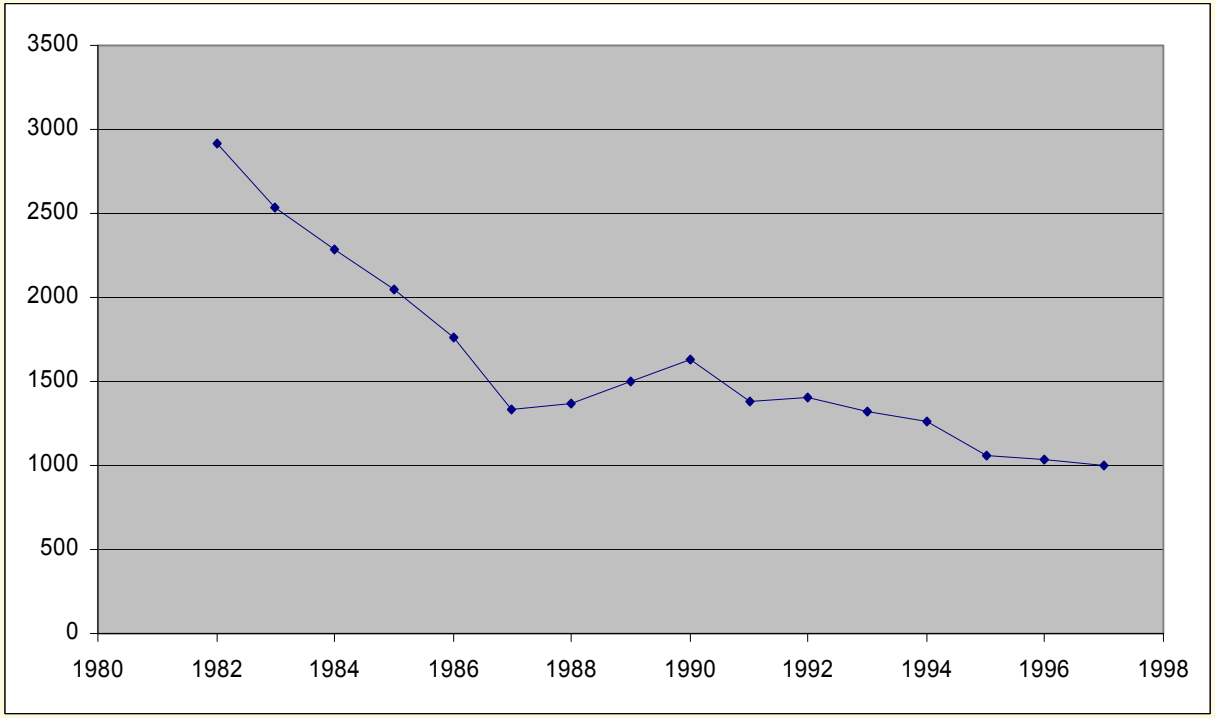
Cost development for solar and wind

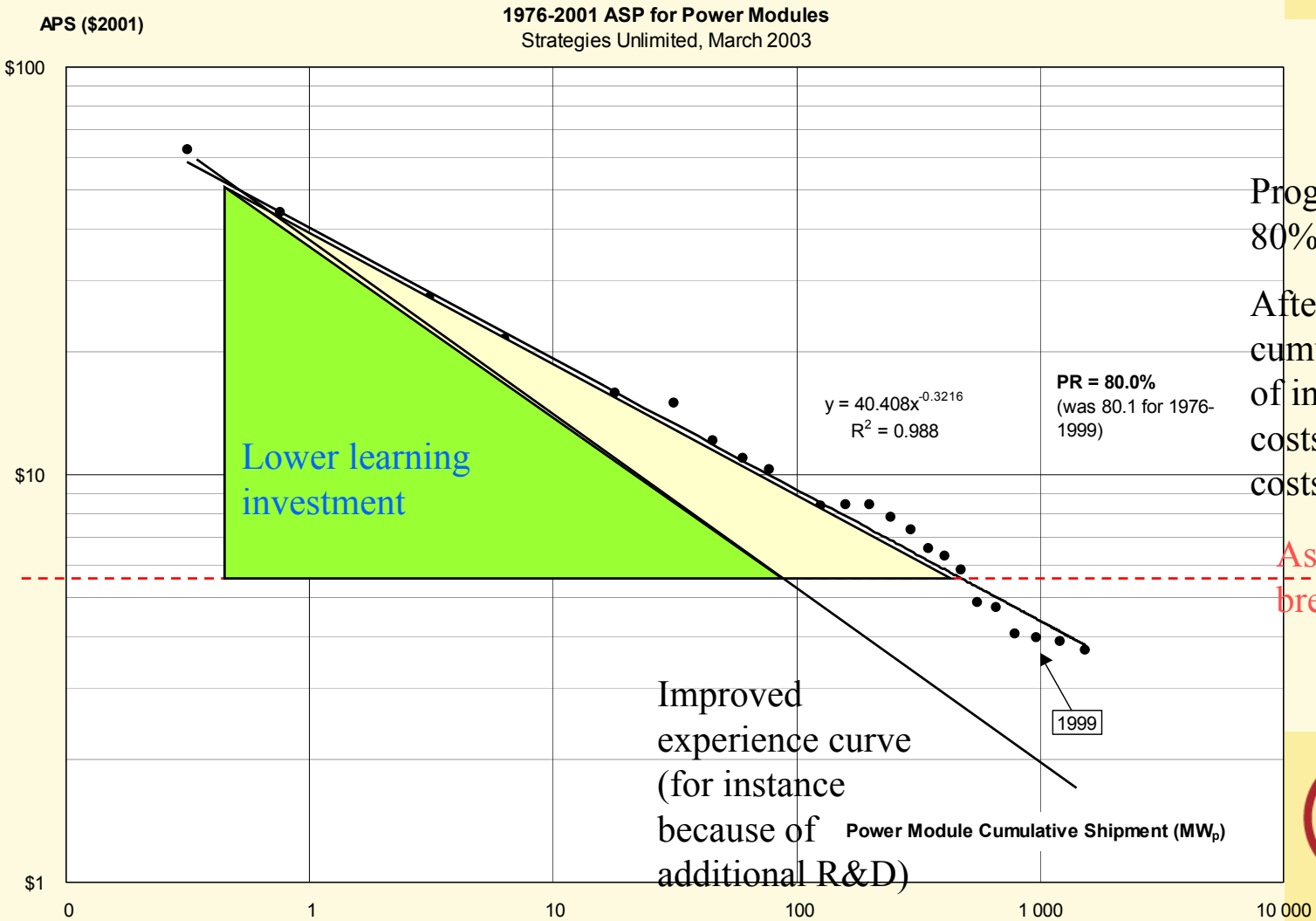
Solar-PV



Wind



The learning curve



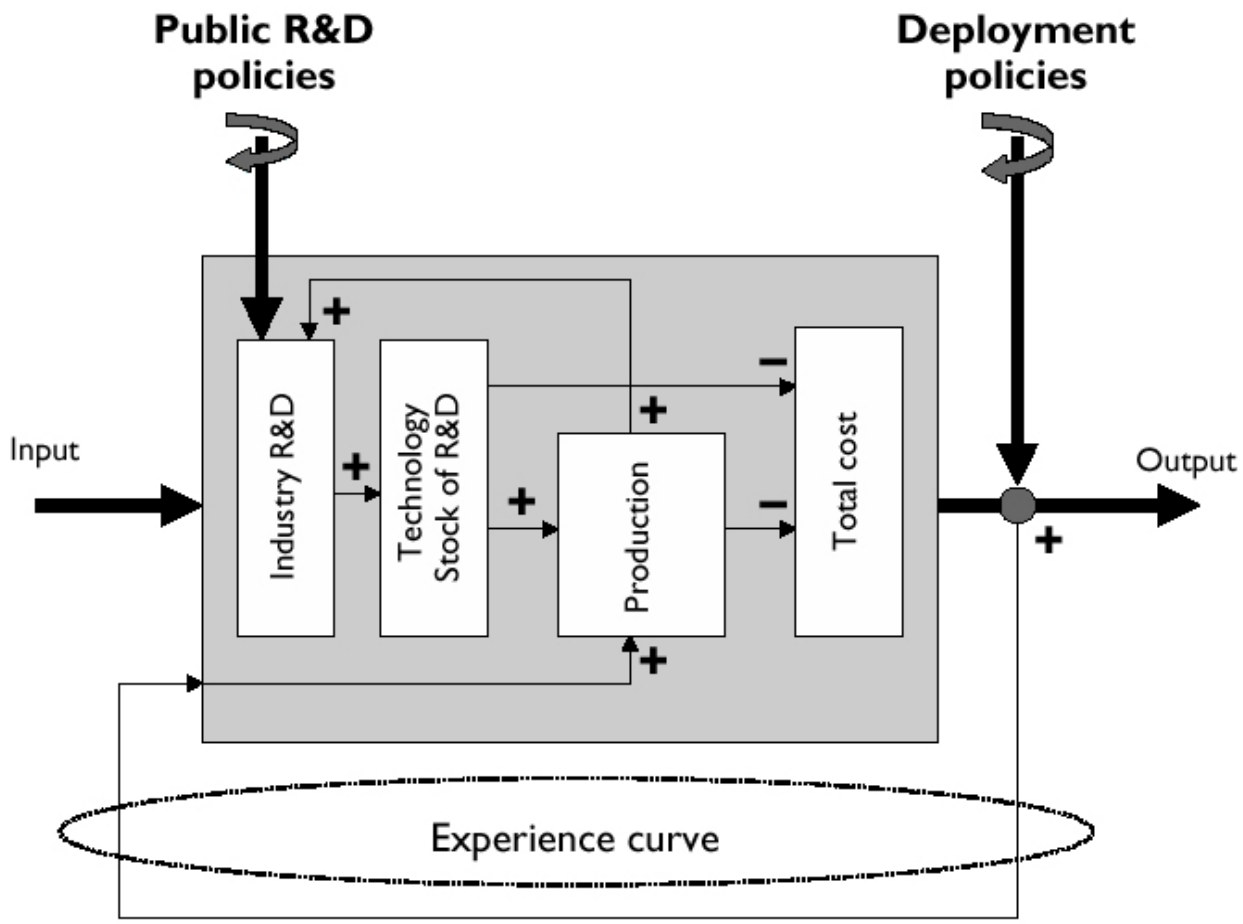
Progress ratio = 80%

After each cumulative doubling of installed capacity costs are just 80% of costs before

Assume, this is break-even

What do we know about learning processes?

Figure 2.2. Influences on the Learning System from Public Policy

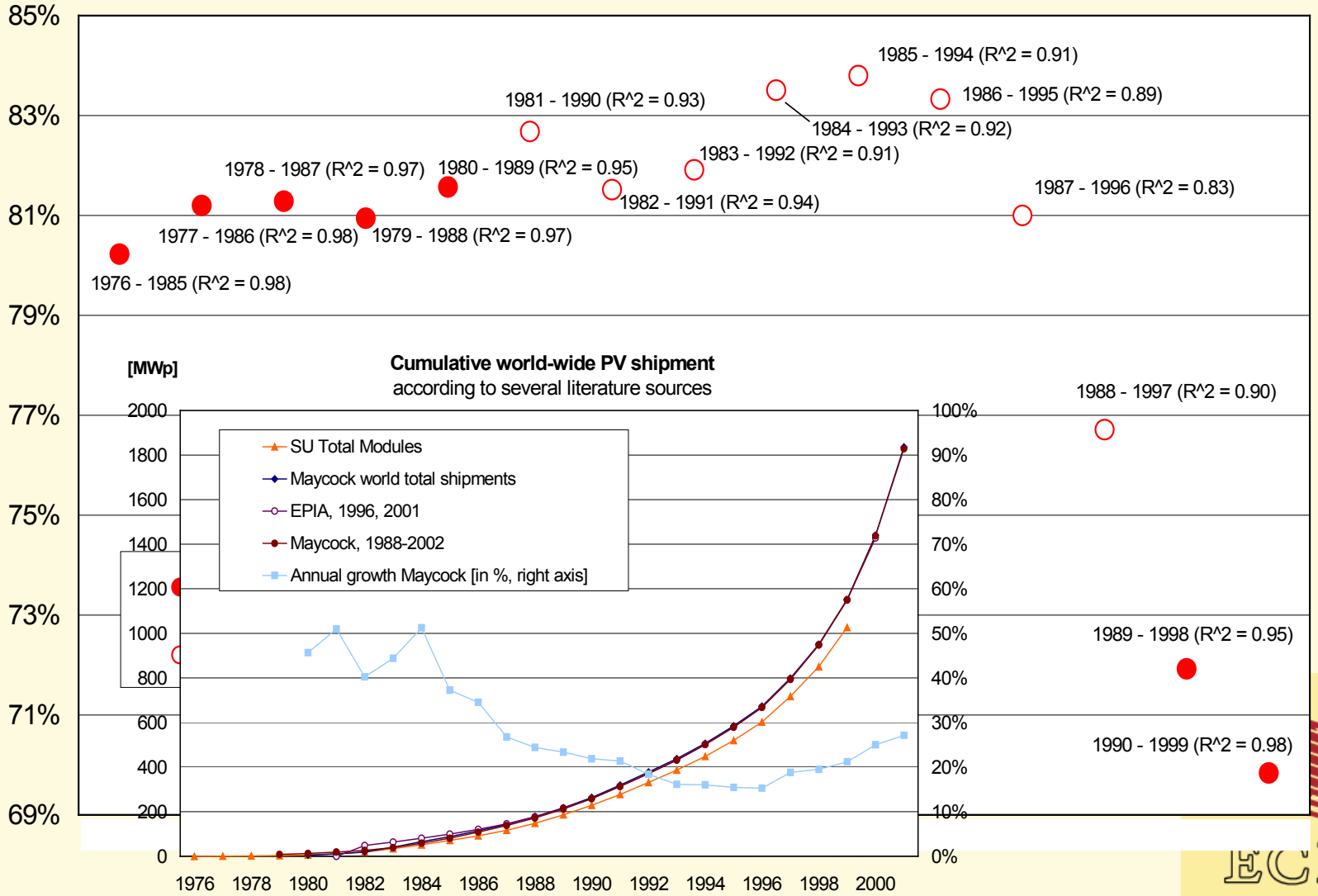


Factors influencing the total cost are taken from Watanabe (1999).

Learning processes

- Occur because of **combination** of R&D and market deployment
- R&D influences progress ratio and thus diminishes the market deployment support needed
- The search is for an optimal mix
  - just market deployment support, or just R&D can be sub-optimal

Progress ratio a.o dependent on growth rate



The right balane for PV: 3 scenarios

	1	2	3
Progress ratio	0.8	0.75	0.65
Growth rate	0.2	0.15	0.1
Results			
break-even year	2044	2045	2044
total learning investment (billions Euro)	1239	310	69
Room for extra R&D-spending (learning improvement) (billions Euro)	0	929	1169
Annual room for additional R&D-spending (learning improvement)	0	21.6	27.8

1974-1998
$ 5 miljard

1= matches history
2= relax market growth, more R&D
3= Strongly R&D-focused

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Lessons

- Question of balance between R&D and deployment support can be addressed
- R&D is needed to at least sustain historical trend
- There is good reason to support also short-term R&D by public money, as long as the technology is supported by market deployment measures
- PV-case: grow a little slower, put some more R&D-money in

Thank you for having me here