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Evaluating Radical Technological Change With an Extended Technology Wedges Approach Based on the GainTech Model

Stefan P. Schleicher

Wegener Center for
Climate and Global Change at the
University of Graz

Angela Köppl

Austrian Institute of
Economic Research, Vienna

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The story line

The radical technological change needed for a low-energy and low-carbon energy system requires an adequate modelling approach
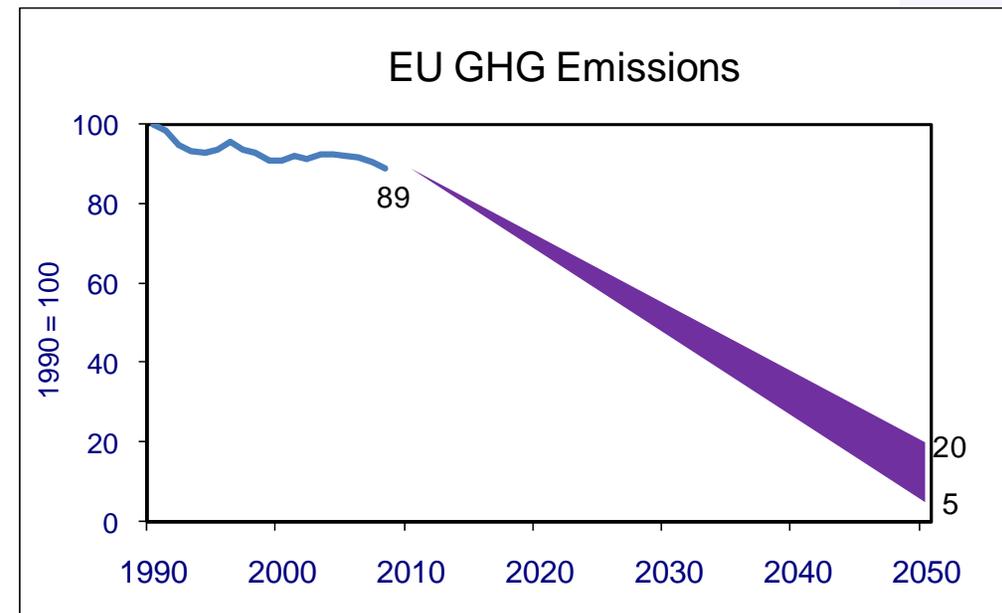
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My agenda

- **The challenge of the EU Roadmaps for 2050**
  - ↗ **Stepping up resource efficiency**
  - ↗ **Reducing GHG emissions by 80%**

- **The challenge of dealing with radical technological change**
  - ↗ **Backcasting from the future**

- **The challenge of developing adequate modeling tools**
  - ↗ **Opening the Black Box of technological change**

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EU policy perspectives for 2020 and 2050

- **A more ambitious reduction target for 2020**
  - ↗ **From 20% to 30%**

- **Roadmaps for 2050**
  - ↗ **80% GHG reductions**

EU GHG Emissions

1990 = 100

100
89
80
60
40
20
20
5
0

1990   2000   2010   2020   2030   2040   2050

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The impact analysis of a 30% target for 2020

- **Commission:**
  Costs are 0.54% of GDP
  - **But what does this mean?**

- **We suggest a more refined cost analysis**
  - **Investment costs – impact over many years**
  - **User costs – per annum**
    Annual capital costs + operating costs

- **Our cost estimates**
  - **Additional investments of more than 2% of GDP will be needed**
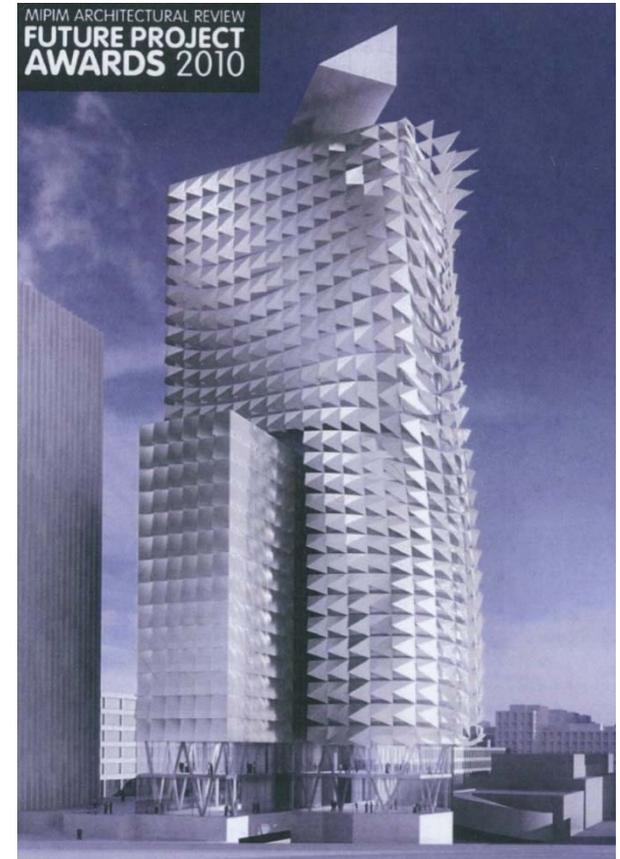 - **But user costs will not necessarily increase**

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The energy system in 2050

Some emerging visions

The transformation of buildings
Almost-zero and plus energy building standards

The transformation of mobility
Plug-in electric cars, self-steering

The transformation of energy supply
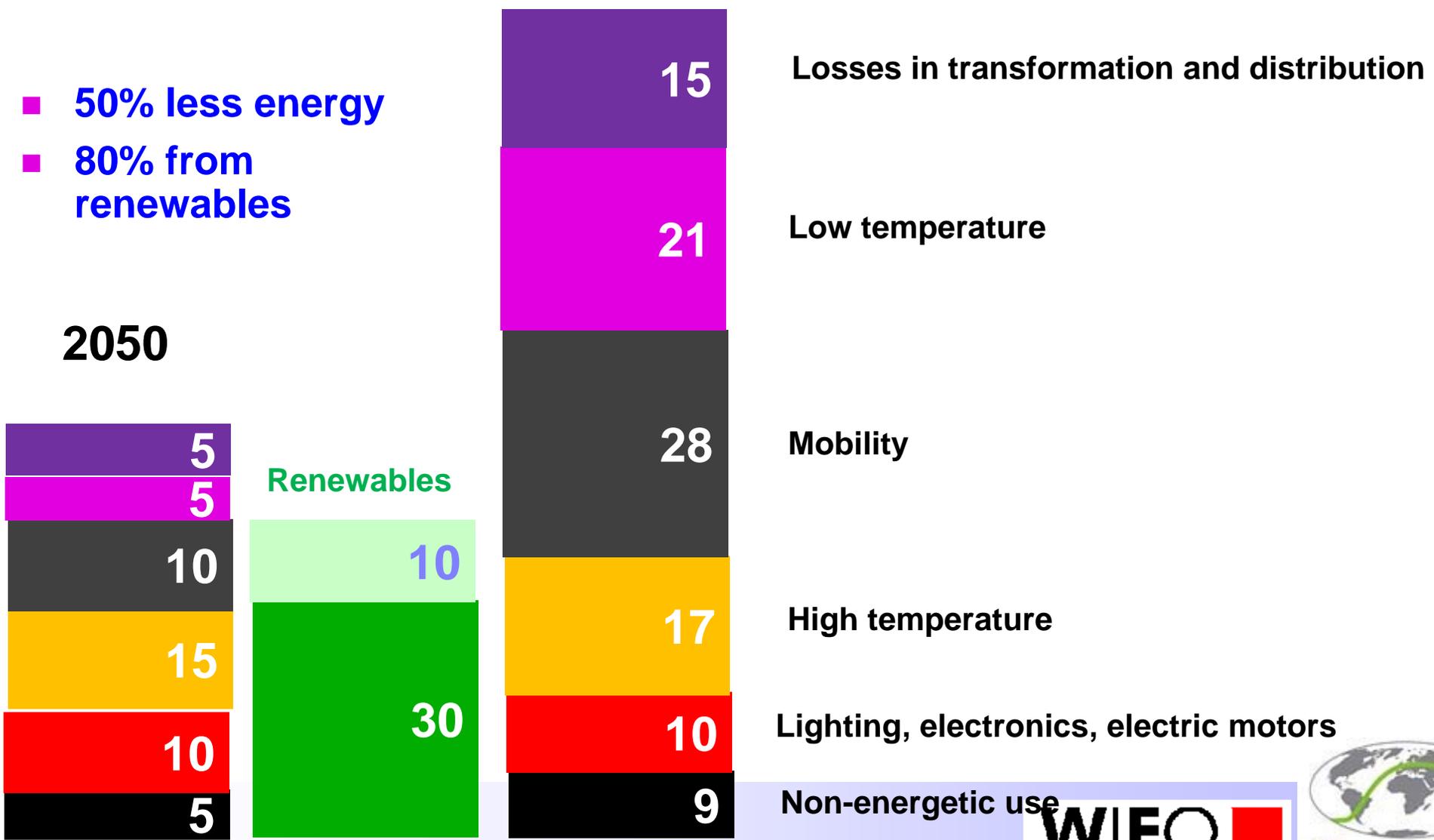## More than 80% from renewables

The big transformation

2010

- **50% less energy**
- **80% from renewables**

2050

Losses in transformation and distribution — 15

Low temperature — 21

Mobility — 28

Renewables — 10, 30

High temperature — 17

Lighting, electronics, electric motors — 10

Non-energetic use — 9

2050: 5, 5, 10, 15, 10, 5

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Modelling radical technological change

The starting point:
Technology wedges approach by
Pacala and Socolow (2004)

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The Pacala & Socolow technology wedges concept
The seminal contribution

- **Latent deficiencies of economic models in treating technologies**
  - Technologies are a "black box"
  - Difficulties in dealing with radical technological changes

- **Technology wedges approach by Stephen Pacala and Robert Socolow (2004)**
  - A highly operational approach for overcoming these latent deficiencies in economic models

  - Stephen Pacala and Robert Socolow (2004).
    Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies
    Science 13 August 2004
    Vol. 305. no. 5686, pp. 968 - 972

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Technology wedges
The Pacala & Solow concept

- **Categorization of available technologies**
  - ⬀ **Efficiency**
  - ⬀ **Decarbonization**
  - ⬀ **Sinks**

- **Scaling technologies by their impact on GHG emissions – the technology wedges**

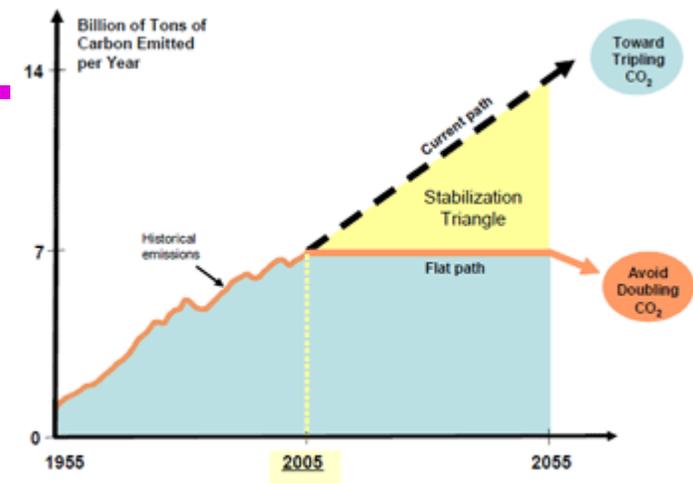- **Applying different combinations of technology wedges to a business-as-usual reference scenario**

Billion of Tons of Carbon Emitted per Year

14

7

0

1955   2005   2055

Historical emissions

Current path

Stabilization Triangle

Flat path

Toward Tripling CO$_2$

Avoid Doubling CO$_2$

Figure 1

Current path

Stabilization Triangle

1 "wedge"

Flat path

7 wedges are needed to build the stabilization triangle

1 wedge avoids 1 billion tons of carbon emissions per year by 2054

Figure 2

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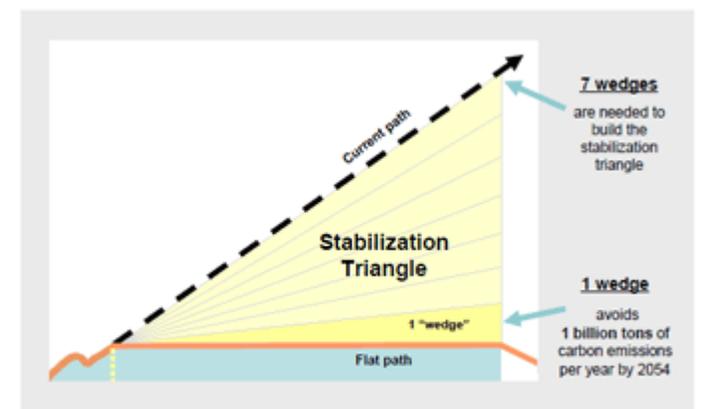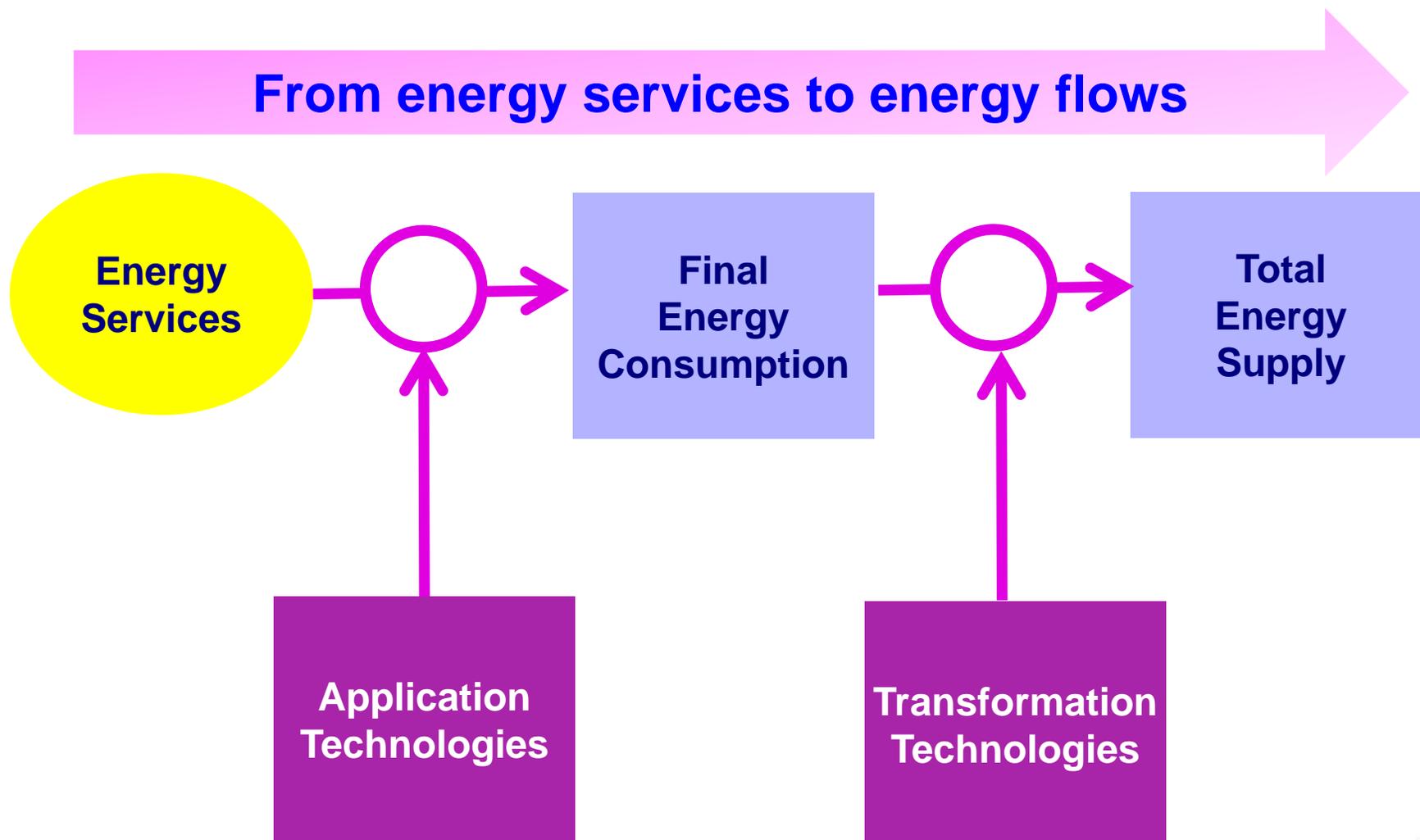
Modelling radical technological change

The extensions:

Embedding technology wedges into the cascade structure of an energy system

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Modeling the cascade structure of the energy system
Extension 1

Defining scalable unit technologies
Extension 2

- **Unit technologies are structured according to their position on the energy cascade**

- **Service**
  - ⤴ **e.g. 1.000 km distance travelled by persons or goods**
- **Application**
  - ⤴ **e.g. mode of transportation (car, train, …)**
- **Transformation**
  - ⤴ **e.g. electricity from hydro power**

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Evaluating the impact of unit technologies
Extension 3

- **Technology evaluation matrix**

	Investment	Operating
Flow effects GDP, consumption, employment exports, imports		
Stock effects all types of capital stocks		
Emissions greenhouse gases and others		
Technology learning, spillover, competitiveness, security		

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Backcasting technology transition paths
Extension 4

- **Three-step backcasting procedure**

- **Long-term targets are specified**
  - **e.g. 80% GHG reductions**
- **Trajectories to the present are constructed**
  - **e.g. based on information about dissemination and learning**
- **Economic impacts of these trajectories are traced**
  - **e.g. investment requirements**
  - **e.g. user costs from investment and operating**

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The modelling approach

Implementation in the GainTech Model

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Buildings (1)
From standard low to extreme low energy standards

■ **Implementation of innovative program for residential buildings up to 2020**

■ **Construction costs for low standards in 2010 [€ per m2]**
- ↗ **Single family** — **1450** — **-30% by 2020**
- ↗ **Multi family** — **1150** — **-30% by 2020**

■ **Energy flows** — **65 kWh per m2 and year**

■ **Construction costs for extreme low standards in 2010 [€ per m2]**
- ↗ **Single family** — **1600** — **-30% by 2020**
- ↗ **Multi family** — **1200** — **-30% by 2020**

■ **Energy flows** — **15 kWh per m2 and year**

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Buildings (2)
From standard low to extreme low energy standards

- **Depreciation rate**   **40 years**
- **Interest rate**   **2.5% p.a.**
- **Energy costs**   **145 €/MWh**

User cost per year [€ per m2]	2010	2020
Single-family		
Low	78	60
Extreme low	82	63
Multiy-family		
Low	61	47
Extreme low	62	47

Dynamic profile of unit technologies
Evolution of impacts of investment and operating

t_{i1}

Investment	Operating
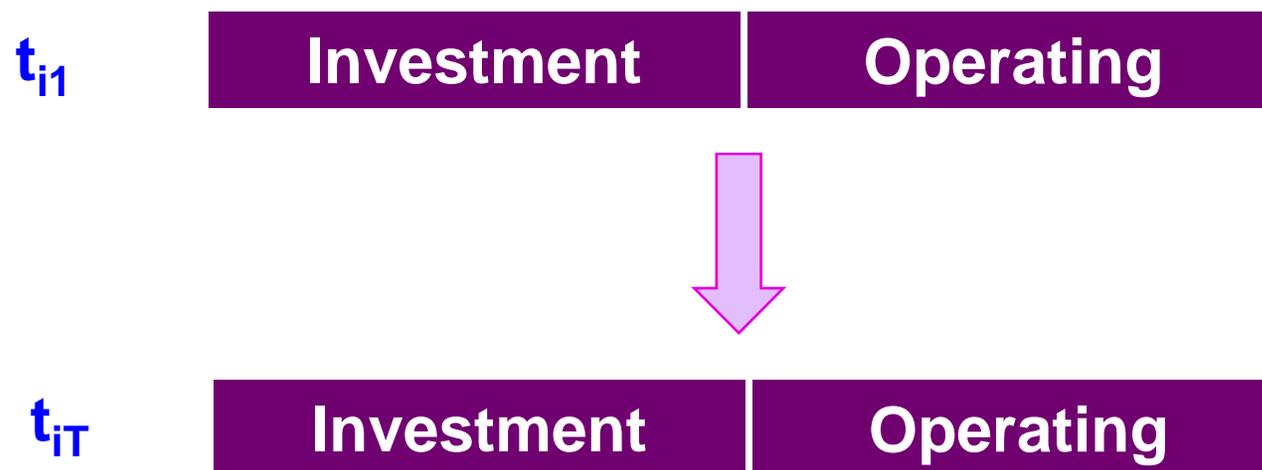
Unit technologies are described by the evolution of their technology evaluation matrix

t_{iT}

Investment	Operating

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Set of unit technologies
Library of available technologies

$t_{1\tau},\ \tau \in T$

$t_{1\tau},\ \tau \in T$
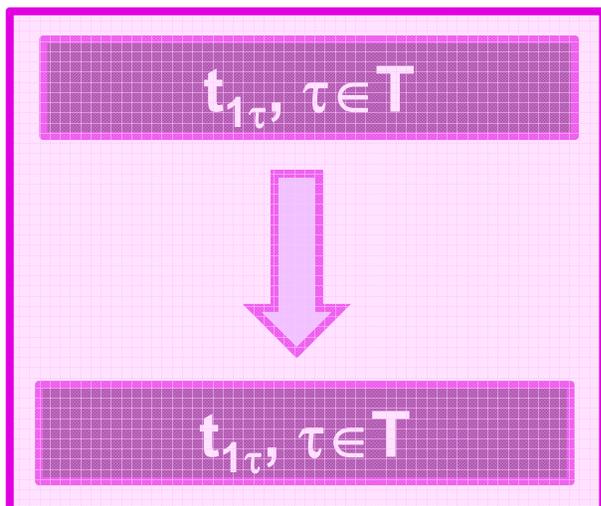
Available unit technologies are put into a library

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Impacts of technology wedge
Time profile of impact indicators

Impact
Indicator

$t_{1\tau}, \tau \in T$

$(t_{j\tau} \cdot x(\tau), \tau \in T)$

$t_{1\tau}, \tau \in T$
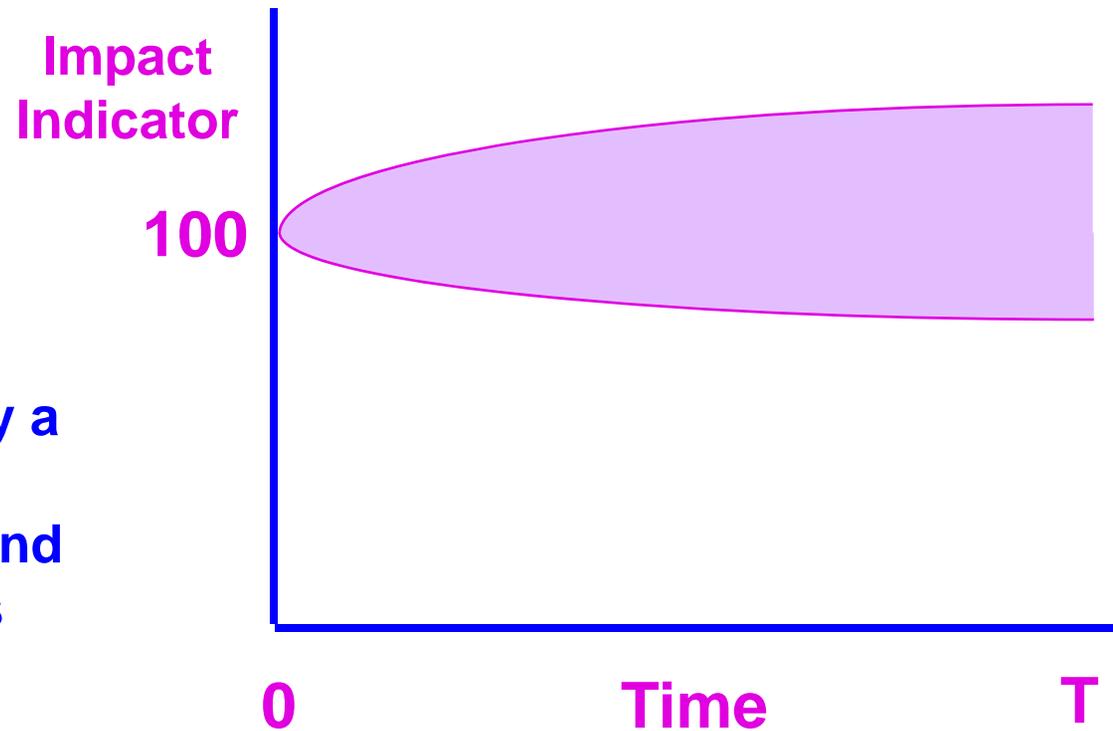
100
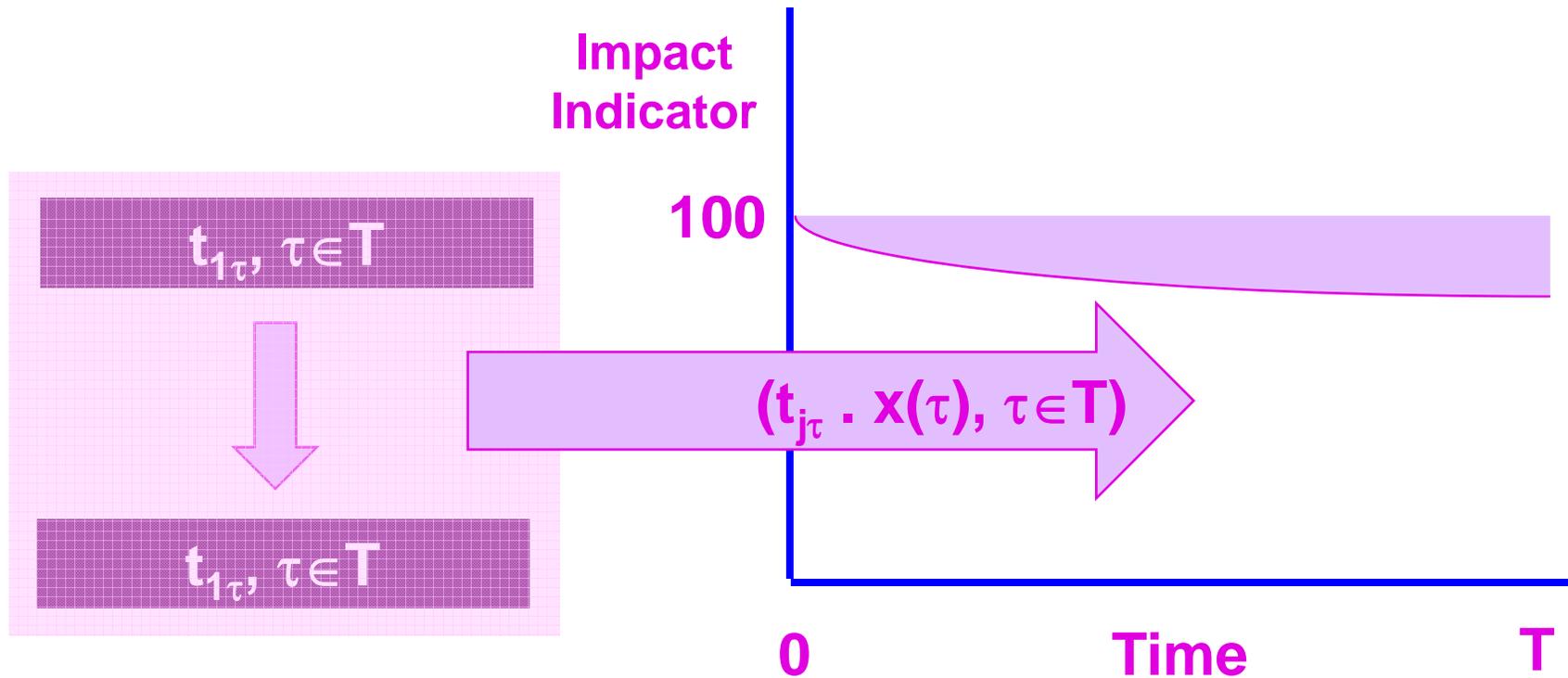
0   Time   T

A particular technology wedge is
defined by its scale and the
diffusion over time

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Technology wedge portfolio
Time profile of impact indicators

Impact Indicator

100

A technology wedge portfolio is defined by a combination of technology wedges and its combined impacts

0   Time   T

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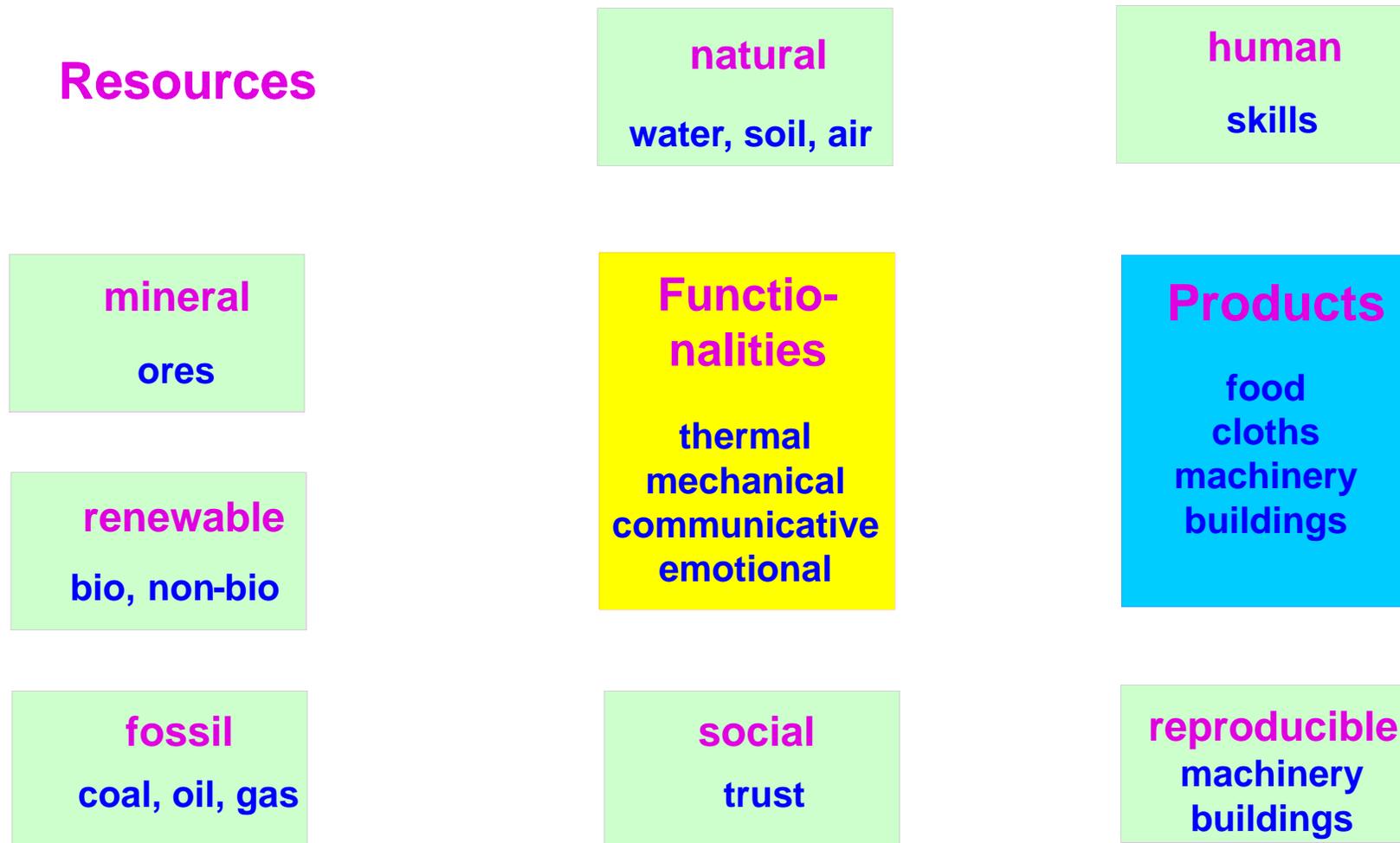# Some specific features of this modeling approach
GainTech: General analysis of innovative technologies

- **Impact and diffusion of technologies**
    - **"Black box" is opened**

- **Wide range of criteria for impact evaluation**
    - **Differentiated cost effects: investment, operating, use**

- **Open to different institutional framework and coordination mechanisms**
    - **Price based and non-priced based environments**

- **New insights into abatement costs**
    - **Based on comparing user costs of different technologies**

- **Implementations**
    - **Energytransition**
    - **Beyond-20**

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The next extension
A "Beyond GDP" modeling framework

Resources

natural

water, soil, air

human

skills

mineral

ores

Functio-nalities

thermal
mechanical
communicative
emotional

Products

food
cloths
machinery
buildings

renewable

bio, non-bio

fossil

coal, oil, gas

social

trust

reproducible

machinery
buildings

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Thank you.

Stefan.Schleicher@wifo.at
http://Stefan.Schleicher.wifo.at
@SPSchleicher

Wegener Center for
Climate and Global Change at the
University of Graz

Austrian Institute of
Economic Research, Vienna