Expert elicitation of RD&D uncertain effectiveness on energy innovation

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Innovation for climate change mitigation: a study of energy R&D, its uncertain effectiveness and Spillovers

Purpose of the seminar

Characteristics and results of 3 expert elicitation (EE) processes on energy technologies. Focus on:

- strengths of our protocol
- main critical factors which introduced biases and lack of correlation in the estimates
- key features for designing more effective elicitation processes, focusing on energy technologies.

Our research builds upon the existing applications of EE to carbon-free energy technologies (1). Innovative elements :

- First elicitation of *European* experts;
- Experts with different *backgrounds* (academia; institution; private sector);
- Potential of solar/biofuel/battery technologies *worldwide*;
- Assessment of different technology options (e.g. *both PV and CSP* technologies, and *both EVs and PHEVs* vehicles);
- Analysis of the *non-technical conditions* that could set back the *technology diffusion* into the market;
- Double question of costs.

(1) See e.g Baker et al., 2009a; Baker et al., 2009b; Baker et al.; 2009c; Curtright et al., 2008; Chan et al., 2010; Baker et al., 2010; Baker and Keisler, 2011.

The ICARUS project

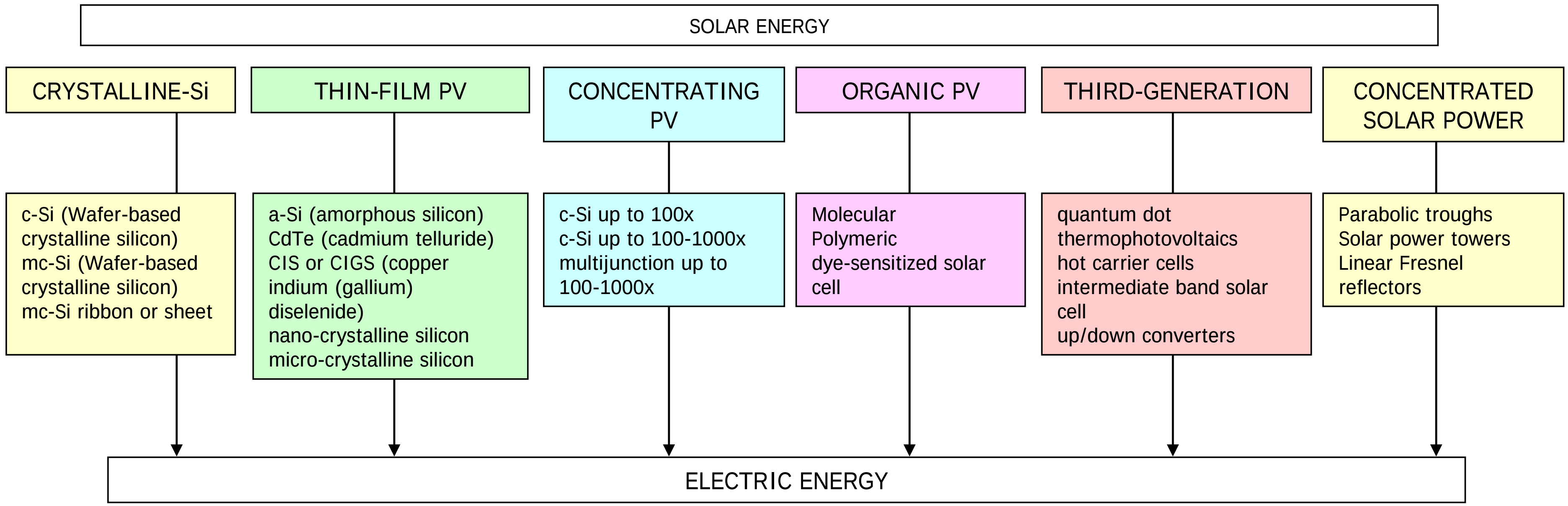
ICARUS ("Innovation for Climate chAnge mitigation: a study of energy R&D, its Uncertain effectiveness and Spillovers") www.icarus-project.org.

1. Understanding the dynamics and drivers of innovation and knowledge flow using different data inputs;
2. Eliciting European experts' opinion on the likelihood of reaching commercial success and diffusion;
3. Assessing optimal energy R&D portfolios under different climate targets in face of both innovation and policy uncertainty (WITCH model).

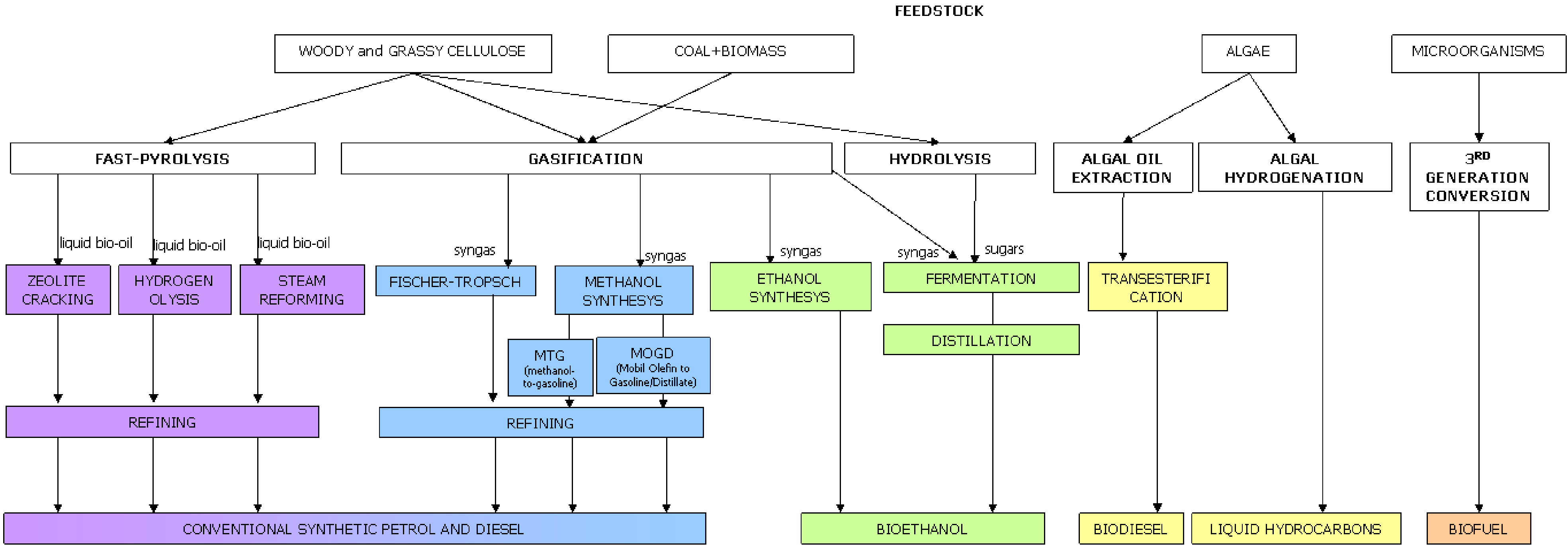
Technologies

- Biofuels for transportation
- Storage for transportation (EDV)
- Solar technologies (PV and CSP)
- Nuclear (with Harvard)
- Bioenergy
- CCS (with University of Massachusetts)

Solar Photovoltaic (PV) and Concentrated Solar Power (CSP)

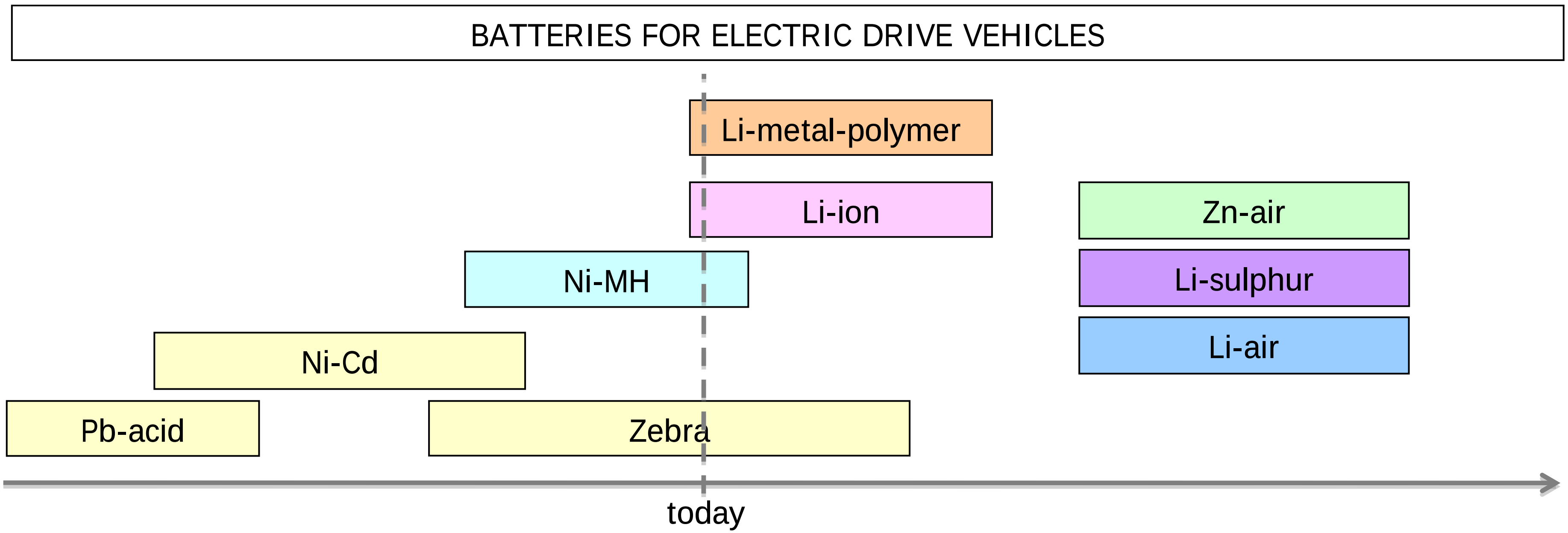


Biofuels

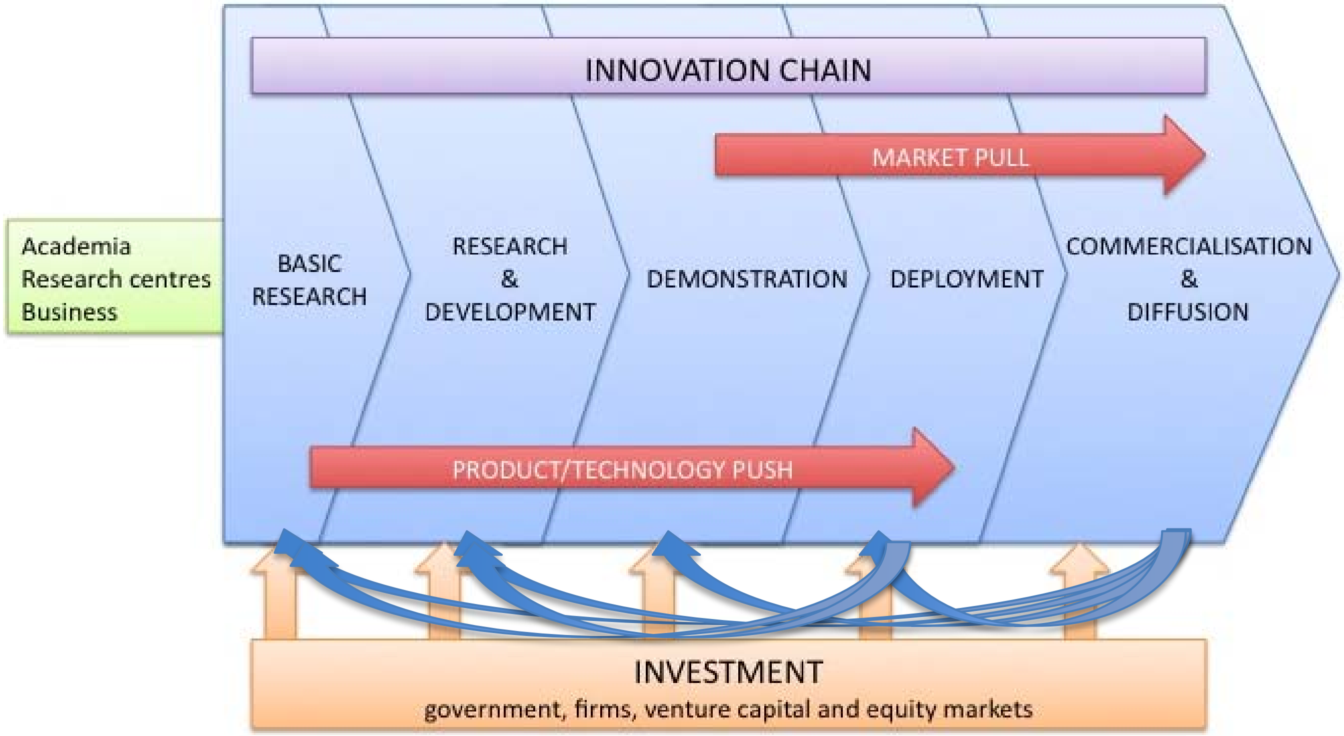


FEEDSTOCK
WOODY and GRASSY CELLULOSE
COAL+BIOMASS
ALGAE
MICROORGANISMS
FAST-PYROLYSIS
GASIFICATION
HYDROLYSIS
ALGAL OIL EXTRACTION
ALGAL HYDROGENATION
3RD GENERATION CONVERSION
liquid bio-oil
liquid bio-oil
liquid bio-oil
syngas
syngas
syngas
syngas
sugars
ZEOLITE CRACKING
HYDROGEN OLYSIS
STEAM REFORMING
FISCHER-TROPSCH
METHANOL SYNTHESYS
ETHANOL SYNTHESYS
FERMENTATION
TRANSESTERIFI CATION
DISTILLATION
MTG (methanol-to-gasoline)
MOGD (Mobil Olefin to Gasoline/Distillate)
REFINING
REFINING
CONVENTIONAL SYNTHETIC PETROL AND DIESEL
BIOETHANOL
BIODIESEL
LIQUID HYDROCARBONS
BIOFUEL

Batteries for Electric Vehicles (EVs)



Uncertainty



- **Uncertainty relationship** between RD&D effort and both technological change and cost improvements.
- **To overcome this lack of information, we surveyed experts** and collected probabilistic information on how future technological development are affected by current RD&D funding, government policy, and other barriers to technology development and diffusion.

Protocol

Introductory assessment

- Selection of the questions areas
- Selection of the experts

Selection of the elicitation components

- Face-to-face interviews
- Estimates of physical/monetary quantities and of probabilities

Elicitation process

- Bias control
- Pilot tests

Analysis procedures

- Follow up sessions
- Analysis of correlation and bias detection
- Assessment of uncertainty
- Use of data/aggregation

(2) Morgan and Henrion, 1990; O'Hagan et al., 2006; Meyer and Booker, 1991; Clemen and Reilly, 2001; Keeney and von Winterfeldt, 1991; Phillips, 1999; Walls and Quigley, 2001.

Critical factors

- Complexity and maturity of each technology;
- Experts' background and expertise;
- Role of Public vs Private investments/reseach.

Effects:

- Biases in the estimates;
- Lack of correlation in the experts' answers.

Questionnaire

Introductory section and self-evaluation questions;

Current state of each technology option;

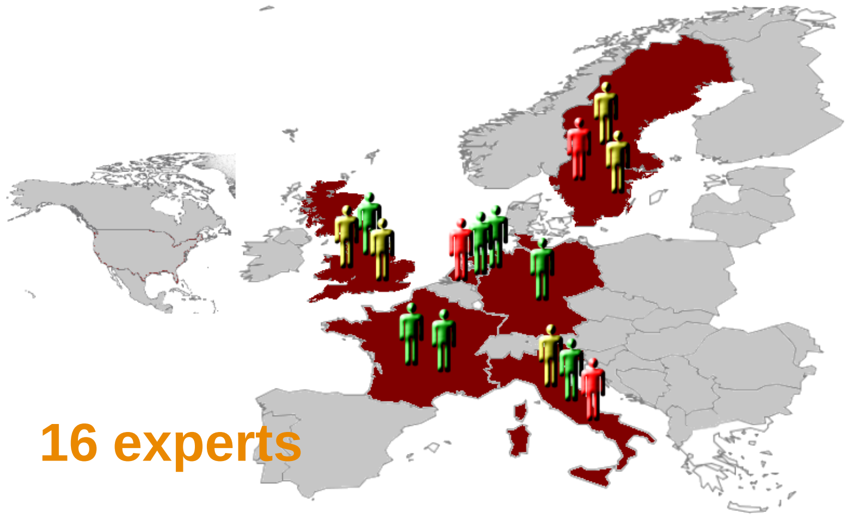
“Optimal” allocation of public R&D funding among the different technology options;

Effect of RD&D funding on the **cost of the technologies (electricity; biofuel production; battery module) in 2030;**

Technology transfer dynamics, diffusion trends and barriers.

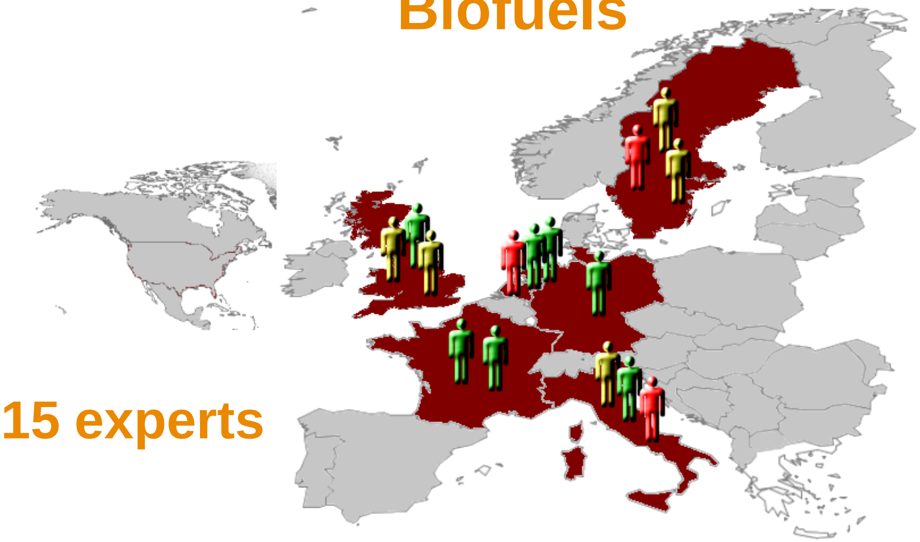
Clusters of experts

Solar PV and CSP

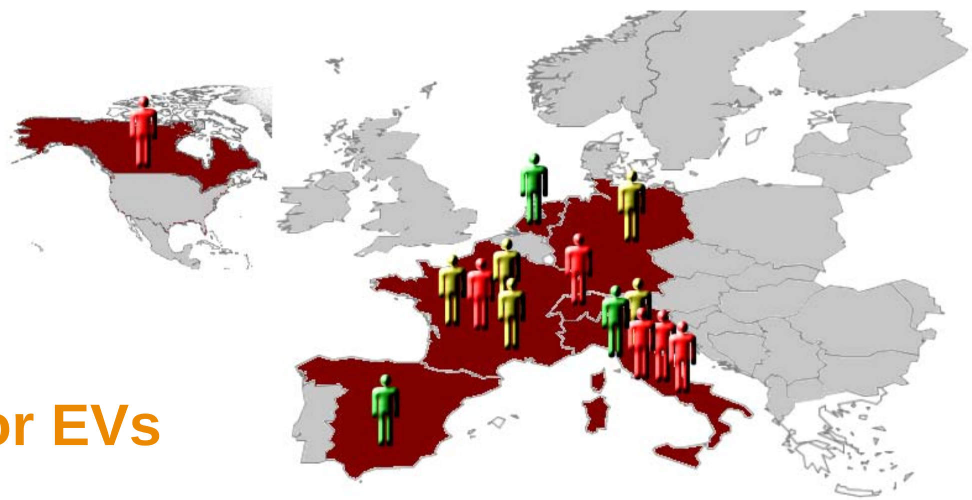


16 experts

Biofuels



15 experts

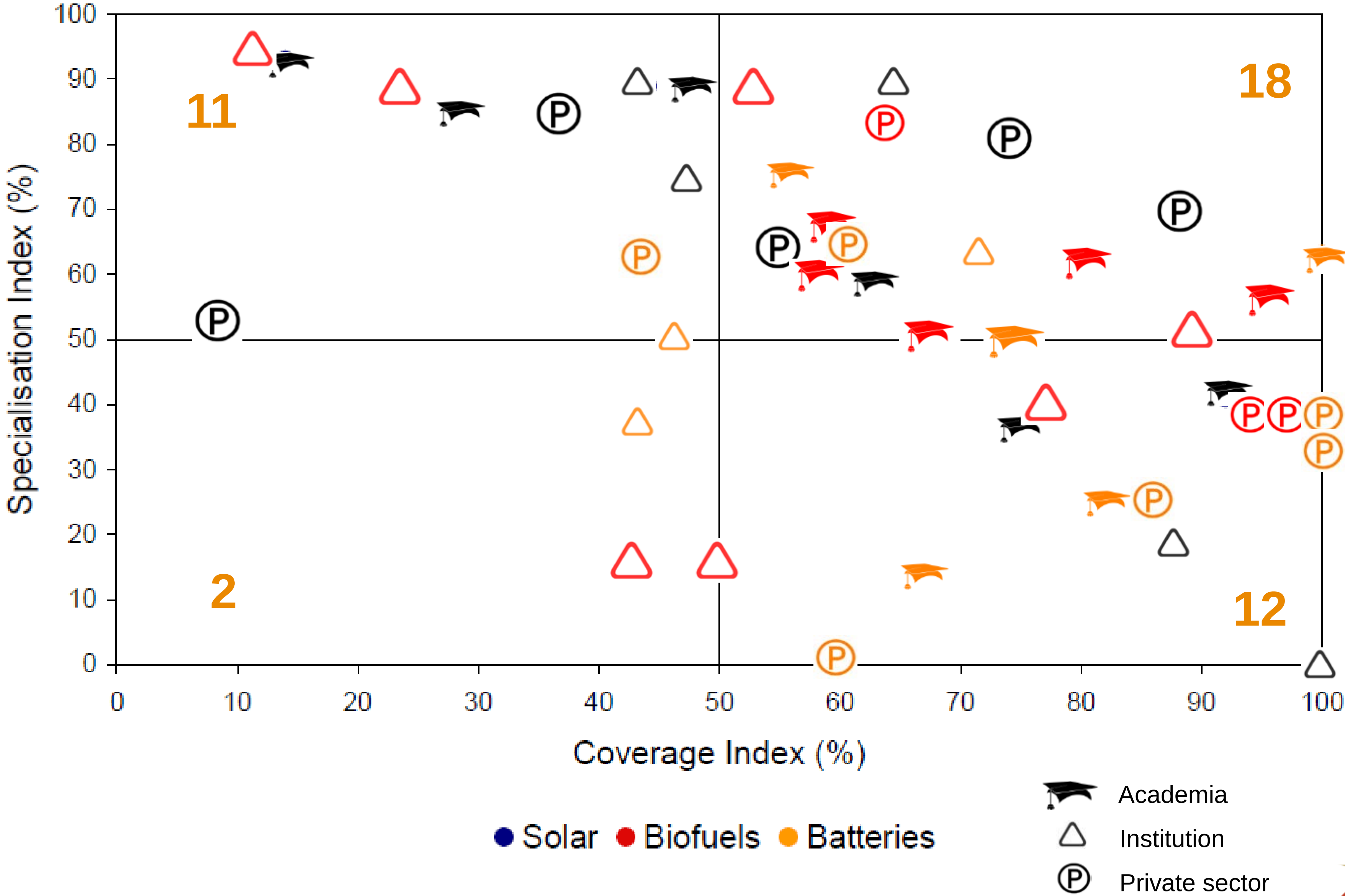


Batteries for EVs

15 experts

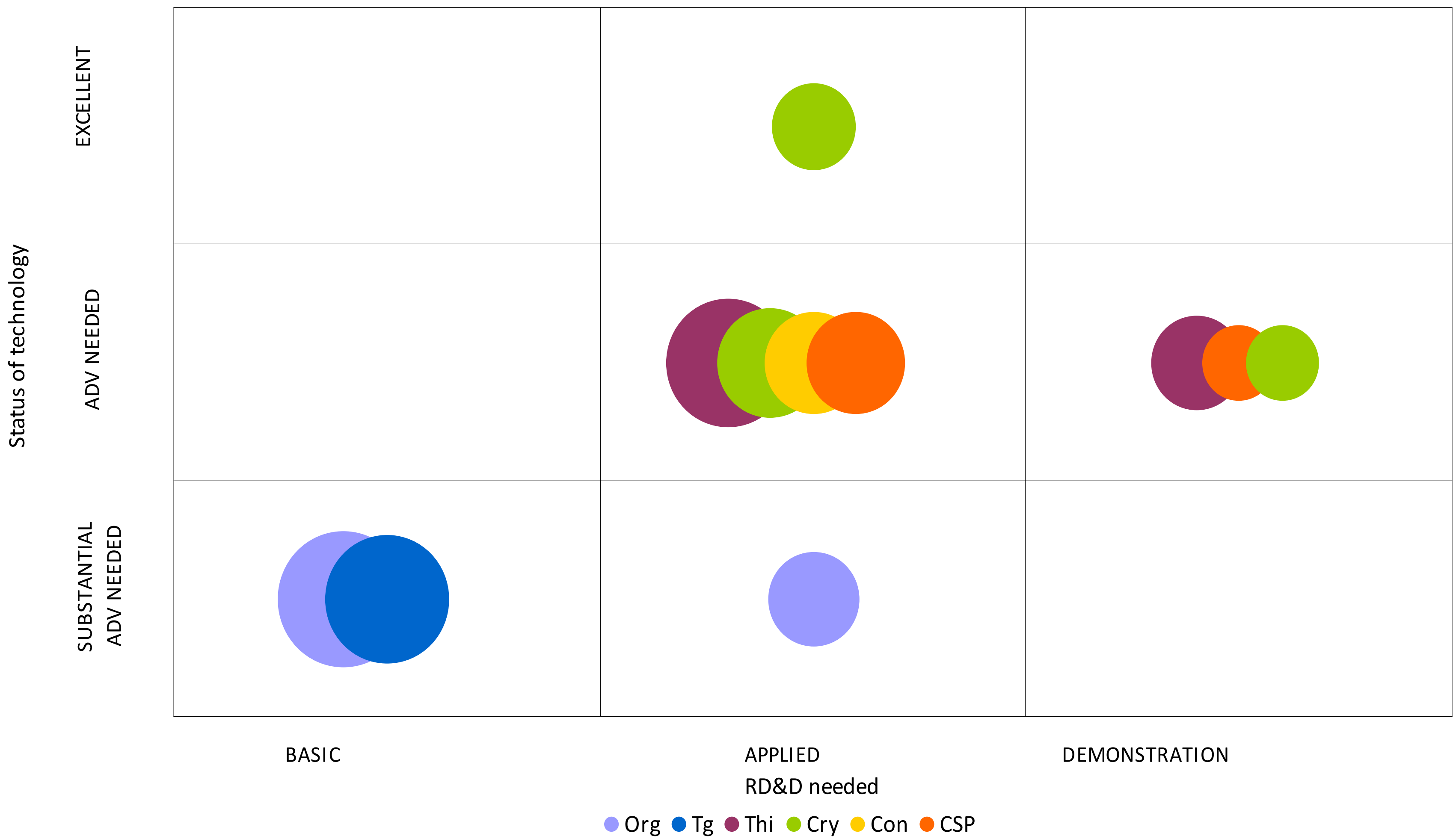
- Institution
- Academy
- Private sector

Expertise

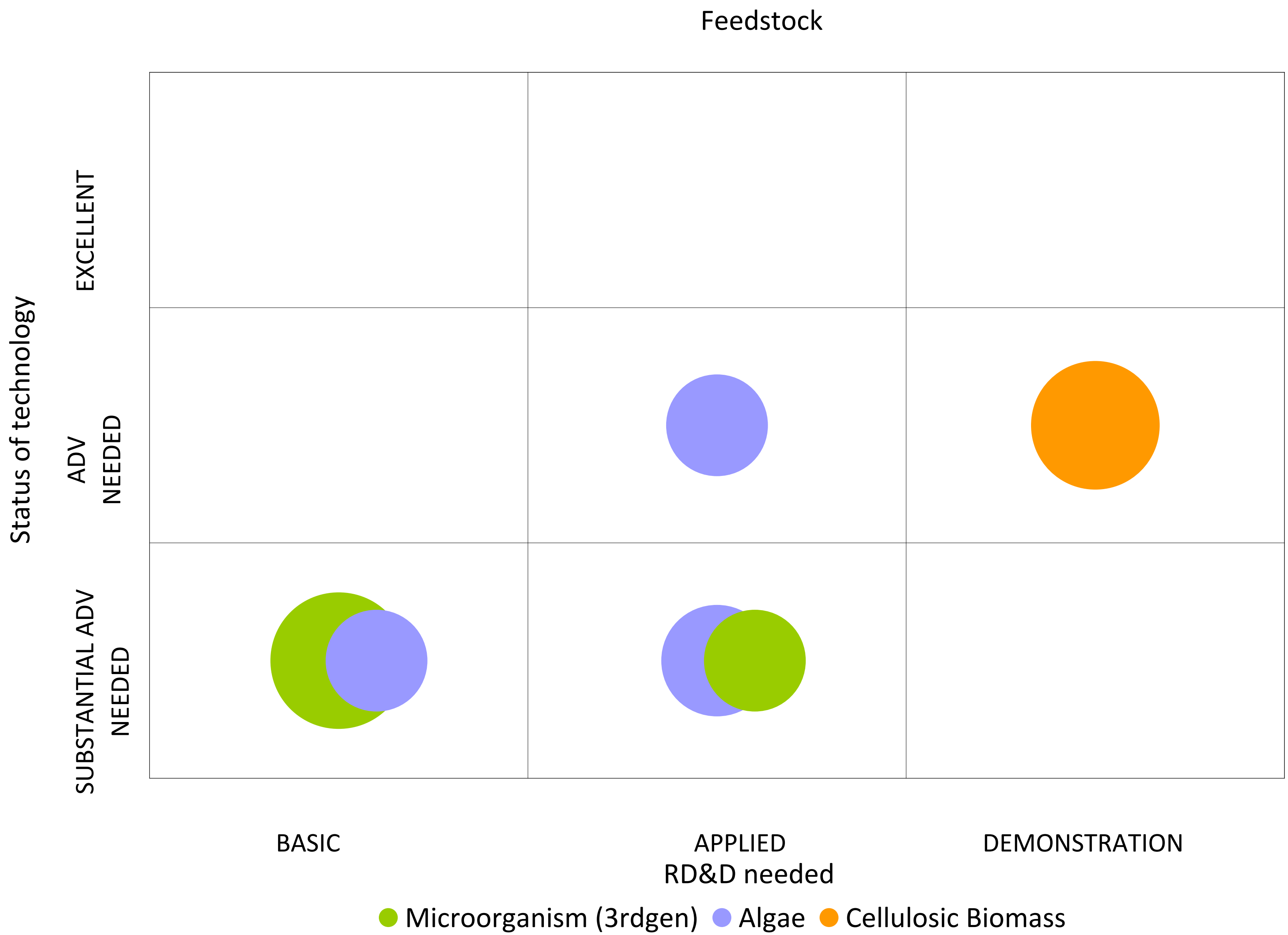


100
90
80
70
60
50
40
30
20
10
0
Specialisation Index (%)
0
10
20
30
40
50
60
70
80
90
100
Coverage Index (%)
11
18
2
12
Academia
Institution
Private sector
Solar
Biofuels
Batteries

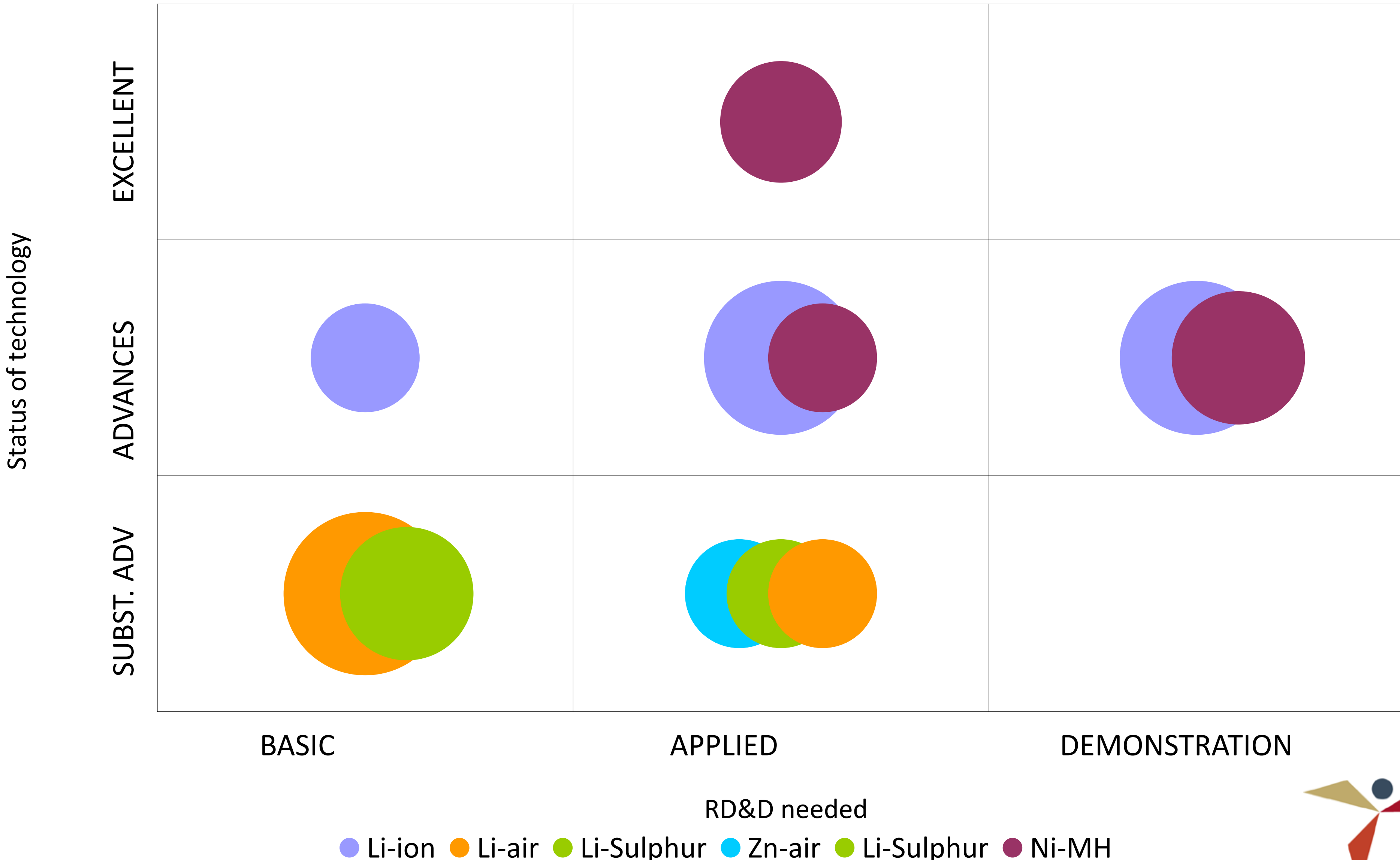
Technology maturity - Solar



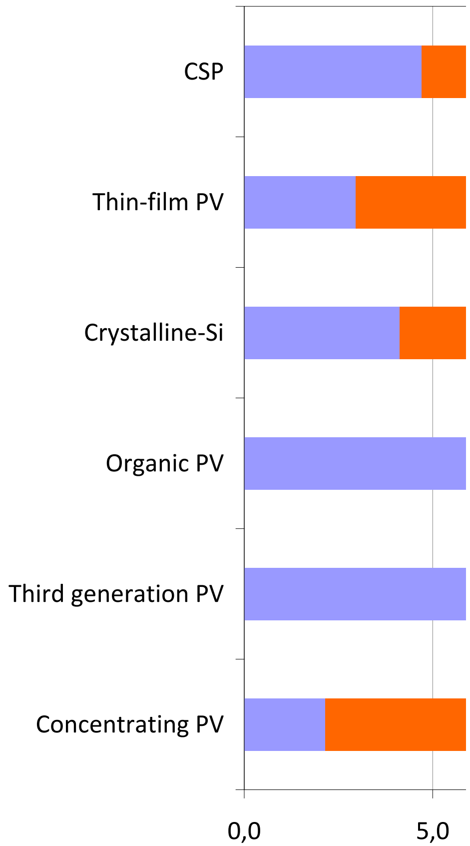
Technology maturity - Biofuels

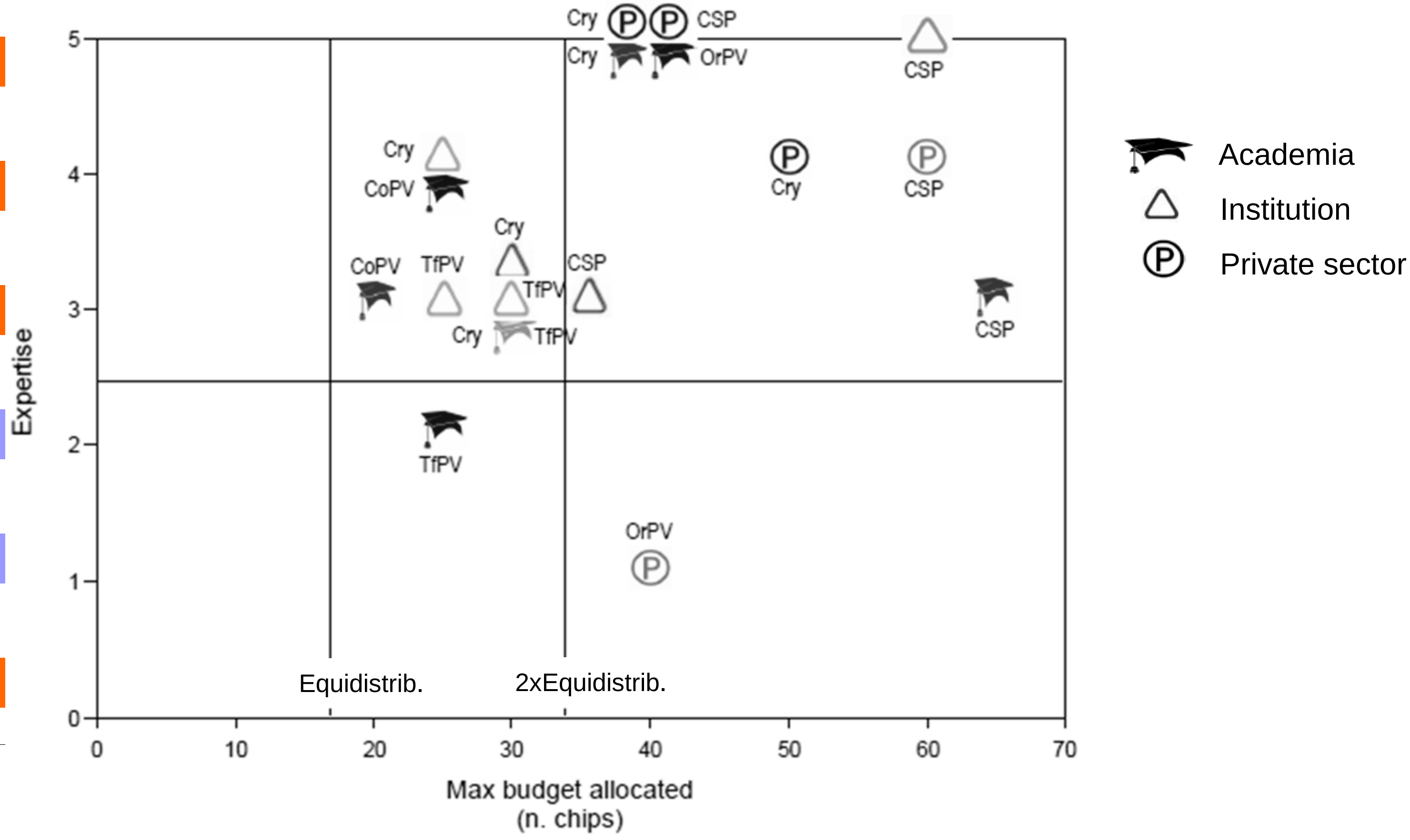


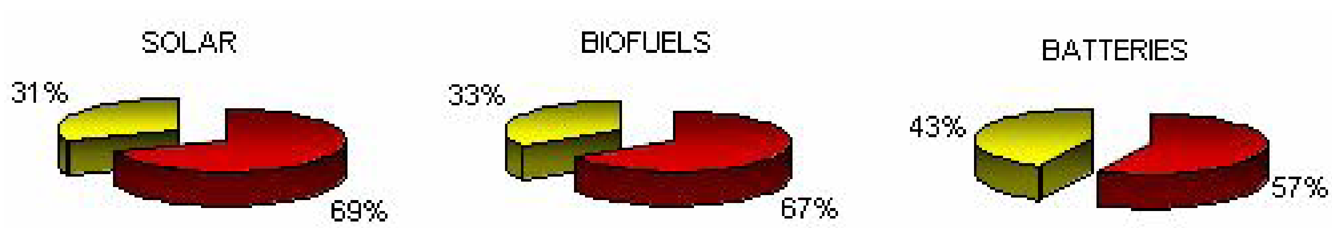
Technology maturity - Batteries



Budget allocation - Solar







Evolution of expected costs under different R&D scenarios

We asked a projection of the expected:

- cost of electricity produced with solar PV or CSP technology (c$/kWh);
- production cost of biofuels ($/liter gasoline equivalent);
- module cost of batteries ($/kWh);

in 2030, under 3 R&D funding scenarios:

- Current yearly amount of R&D expenditures for each year until 2030
- +50% R&D
- +100% R&D

Use of PERCENTILES to minimize the overconfidence bias (10th, 50th, 90th)

Formulae to calculate costs, reasoning in terms of technological endpoints

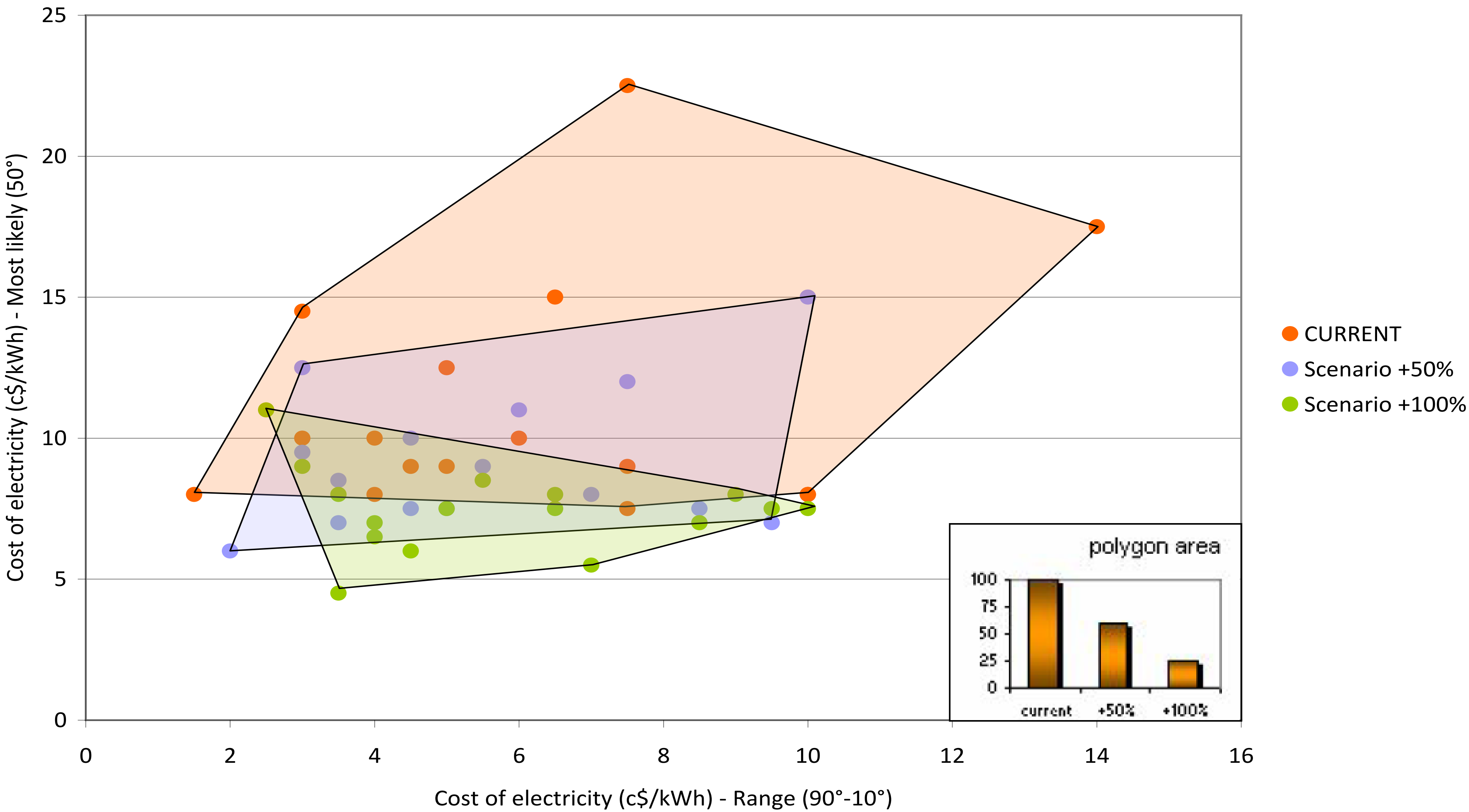
e.g. for Solar PV:

$$C(\$/Wp) = \frac{Module\,areal\,cost(\$/m^2)}{efficiency(\%)\times 1{,}000(Wp/m^2)} + \frac{BOS(\$/m^2)}{efficiency(\%)\times 1{,}000(Wp/m^2)} + CostPower\,Conditioning(\$/Wp)$$

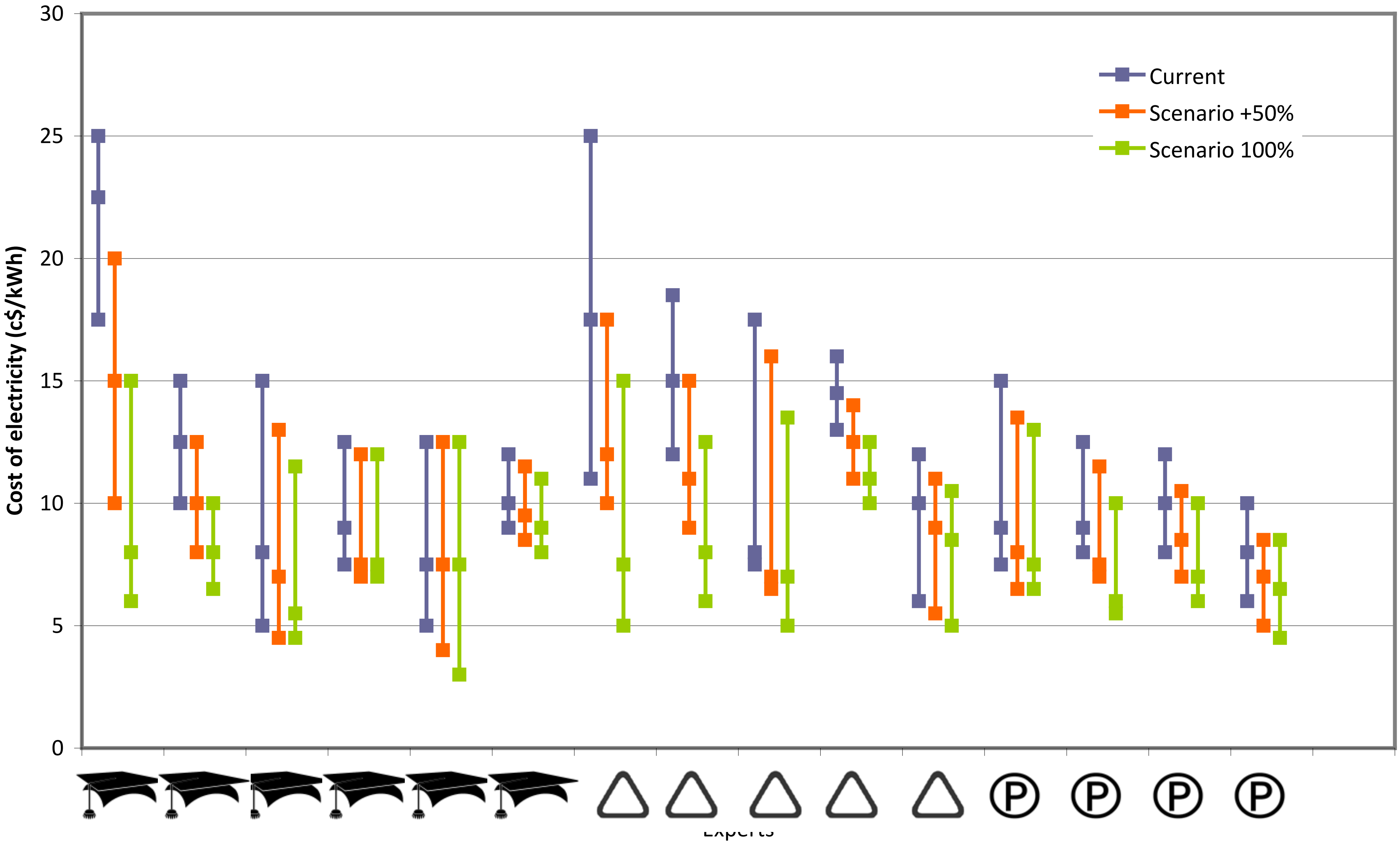
e.g for CSP:

$$C(\$/kWh) = \frac{(FCR \times I) + C_{O\&M}}{E}$$

Costs – Solar (1)



Costs – Solar (2)



Costs

Dual approach:

After eliciting from the experts the direct cost estimates, we questioned them about **the probability to reach the breakthough cost** of:

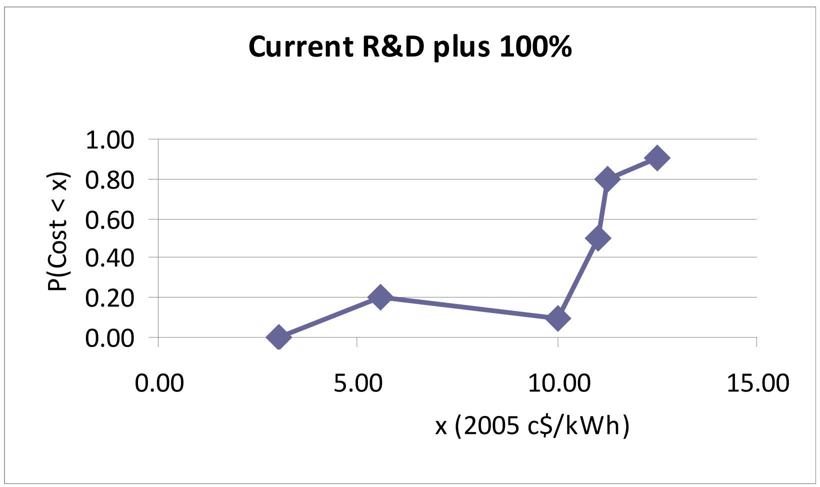
- 11.27 c$/kWh; 5.55 c$/kWh; 3 c$/kWh for electricity generated through solar technology;
- 0.73 $/lge; 0.40 $/lge; 0.20 $/lge for the production cost of biofuel;
- 270 $/kWh; 150 $/kWh for battery module

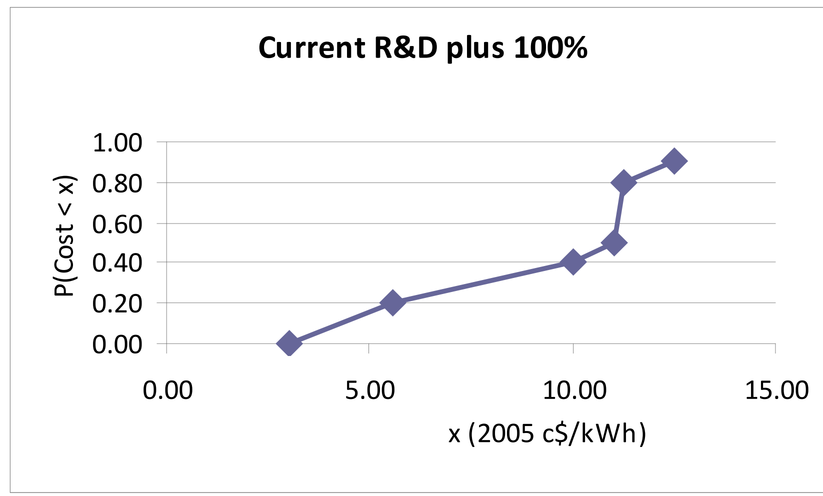
in 2030, under 3 different public R&D investment scenarios (Current; +50%; +100%)

Inconsistencies – Follow up questions

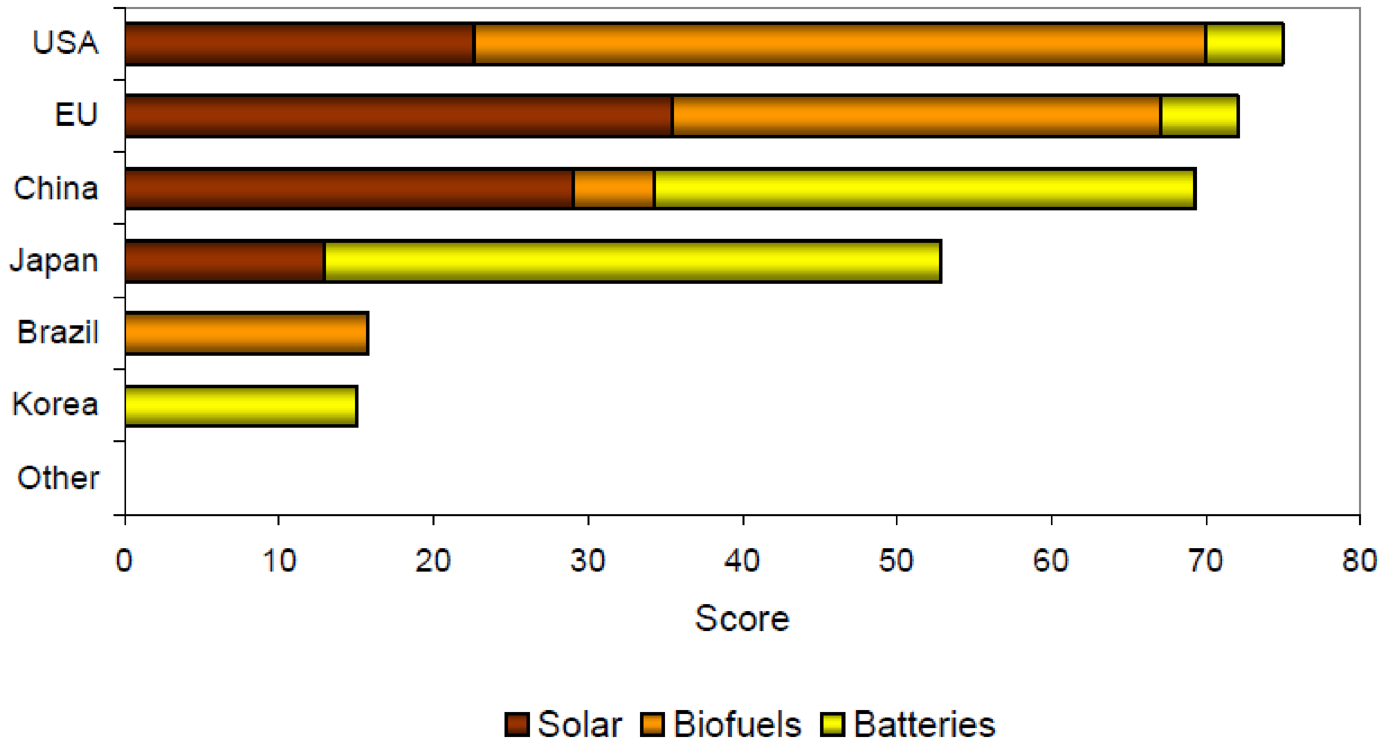
Current R&D plus 100%	
x (c$/kWh)	P(Cost<x)
3.00	0
5.55	0.20
10.00	0.10
11.00	0.50
11.27	0.80
12.50	0.90

Current R&D plus 100% (modified)	
x(c$/kWh)	P(Cost<x)
3.00	0
5.55	**0.20**
10.00	**0.40**
11.00	0.50
11.27	0.80
12.50	0.90

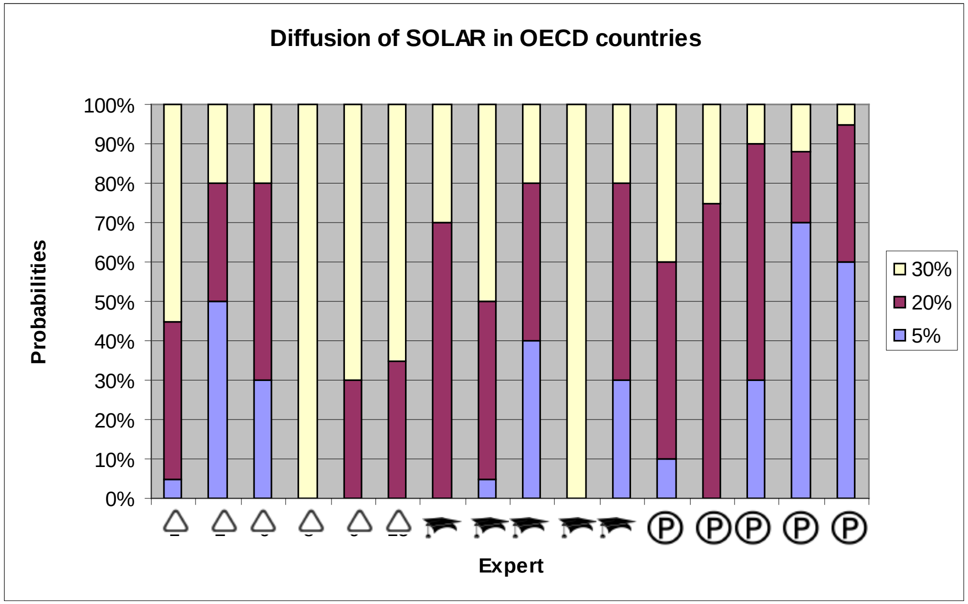


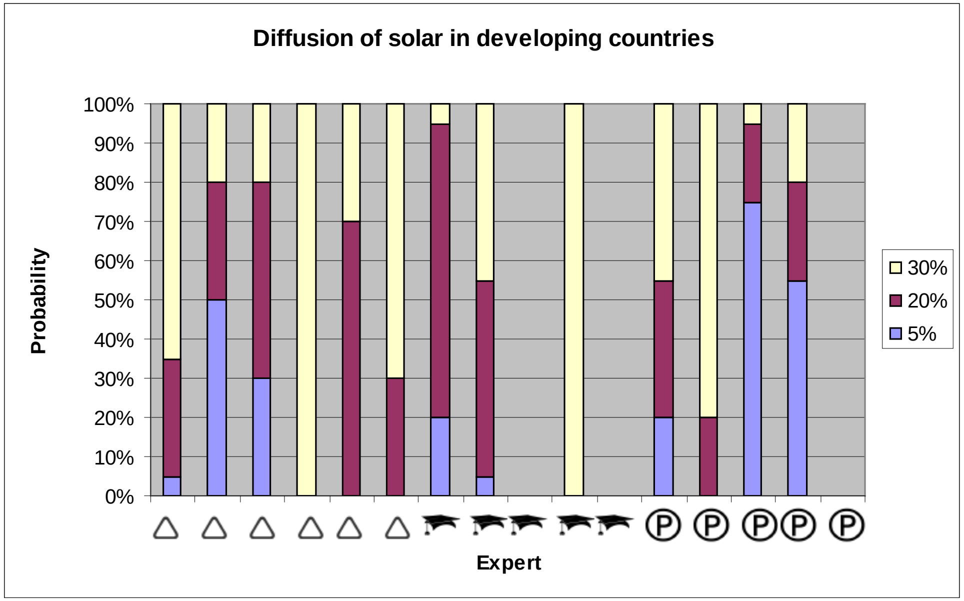


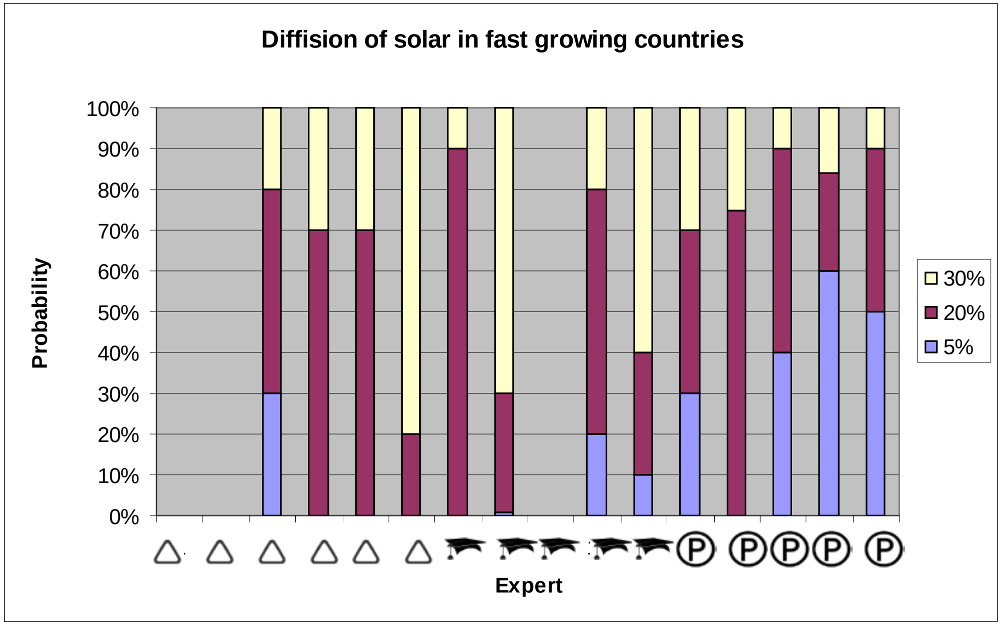
Countries that will first reach the commercial breakthrough



Diffusion scenarios







Concordance among the experts

QUESTION	SOLAR	BIOFUELS	BATTERIES
At least one mature technology path	☹	☺	☹
Barriers which could not be overcome with an increase in RD&D	😐	☹	☺
Direct relationship between an increase in RD&D and a decrease in the cost (of electricity/of fuel/of battery module)	☺	☹	😐
Direct relationship between increase in RD&D and probability of reaching the breakthrough cost	☺	☹	☹
➡ Important role of non-market barriers in limiting the diffusion of the technology	☺	☺	☺
➡ High rate of diffusion (30% solar; 50% biofuels and batteries)	☹	☺	☹
Classes of concordance			
☺ **High concordance (>70%)**	**3**	**3**	**2**
😐 **Medium concordance (60%-70%)**	**1**	**0**	**1**
☹ **No concordance (<60%)**	**2**	**3**	**3**

Critical factors

	experts			*technology*		*data availability*
	Internal balance (background)	Specialization	Coverage	N technology options	Maturity	Institutional involvement (knowledge spillovers)
solar	H	H	M	M	M	M
biofuels	M	M	H	L	H	M
batteries	M	L	M	H	L	L

Conclusions

- First elicitation of *European* experts → Different EU countries; highly heterogeneous institutional realities;

- Experts with different *backgrounds* (academia; institution; private sector) → It affects the results (NB: private sector). Suggestion: consensus building;

- Potential of solar/biofuel/battery technologies *worldwide* → there is no evidence of a country bias;

- Assessment of different technology options (e.g. *both PV and CSP* technologies, and *both EVs and PHEVs* vehicles) → The field of expertise can cause biases. No direct aggregation;

- Analysis of the *non-technical conditions* that could set back the *technology diffusion* into the market → experts are at ease in answering the diffusion questions;

- Double question on costs: it helps!

This work has been done in cooperation with
Dr Valentina Bosetti (ICARUS project Principal Investigator),
Dr Giulia Fiorese (FEEM Senior Researcher),
Dr Elena Verdolini (FEEM Senior Researcher).

THANK YOU

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Thanks

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