MERCURY – Modeling the European power sector evolution: low-carbon generation technologies (renewables, CCS, nuclear), the electric infrastructure and their role in the EU leadership in climate policy

Exploring pathways of solar PV learning in Integrated Assessment Models

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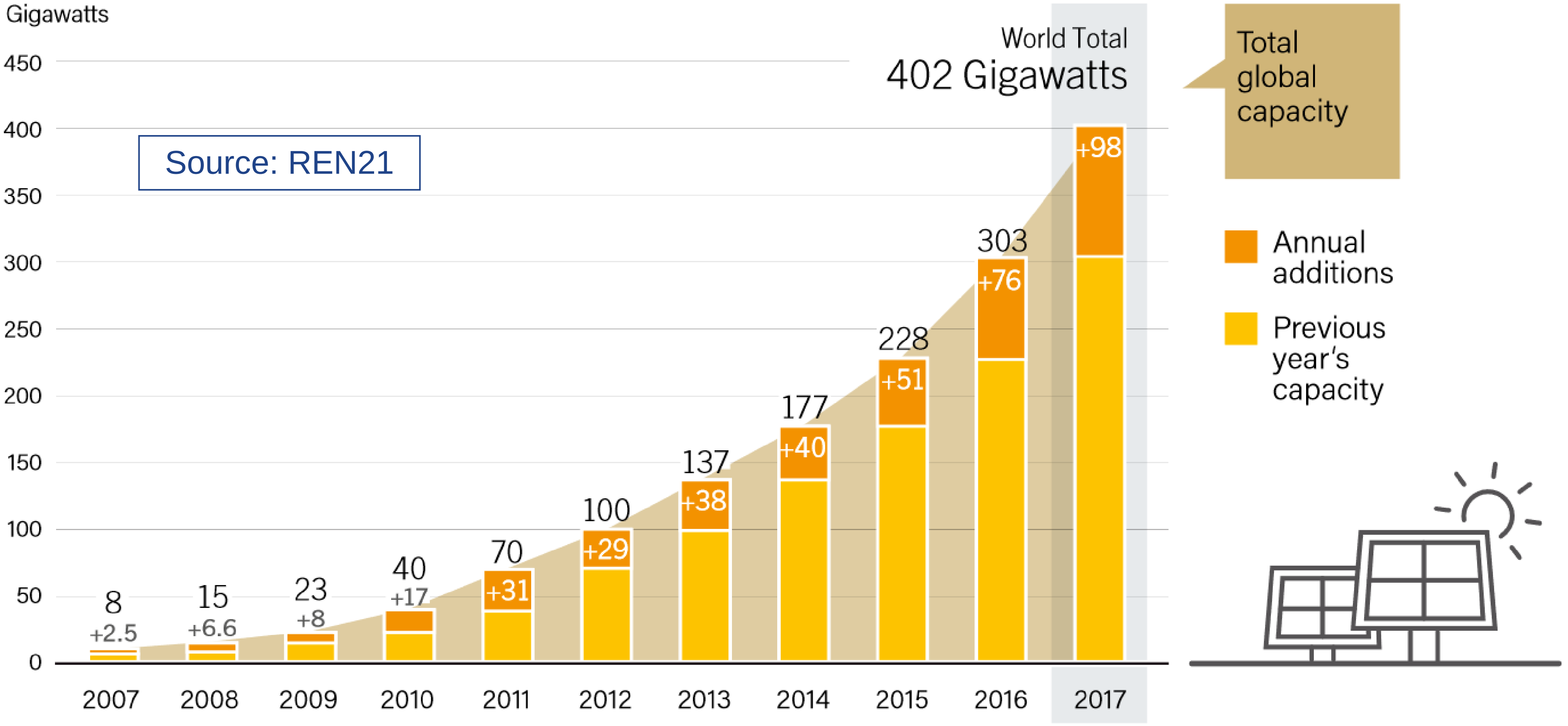
Motivation and Scope I – PV global capacity



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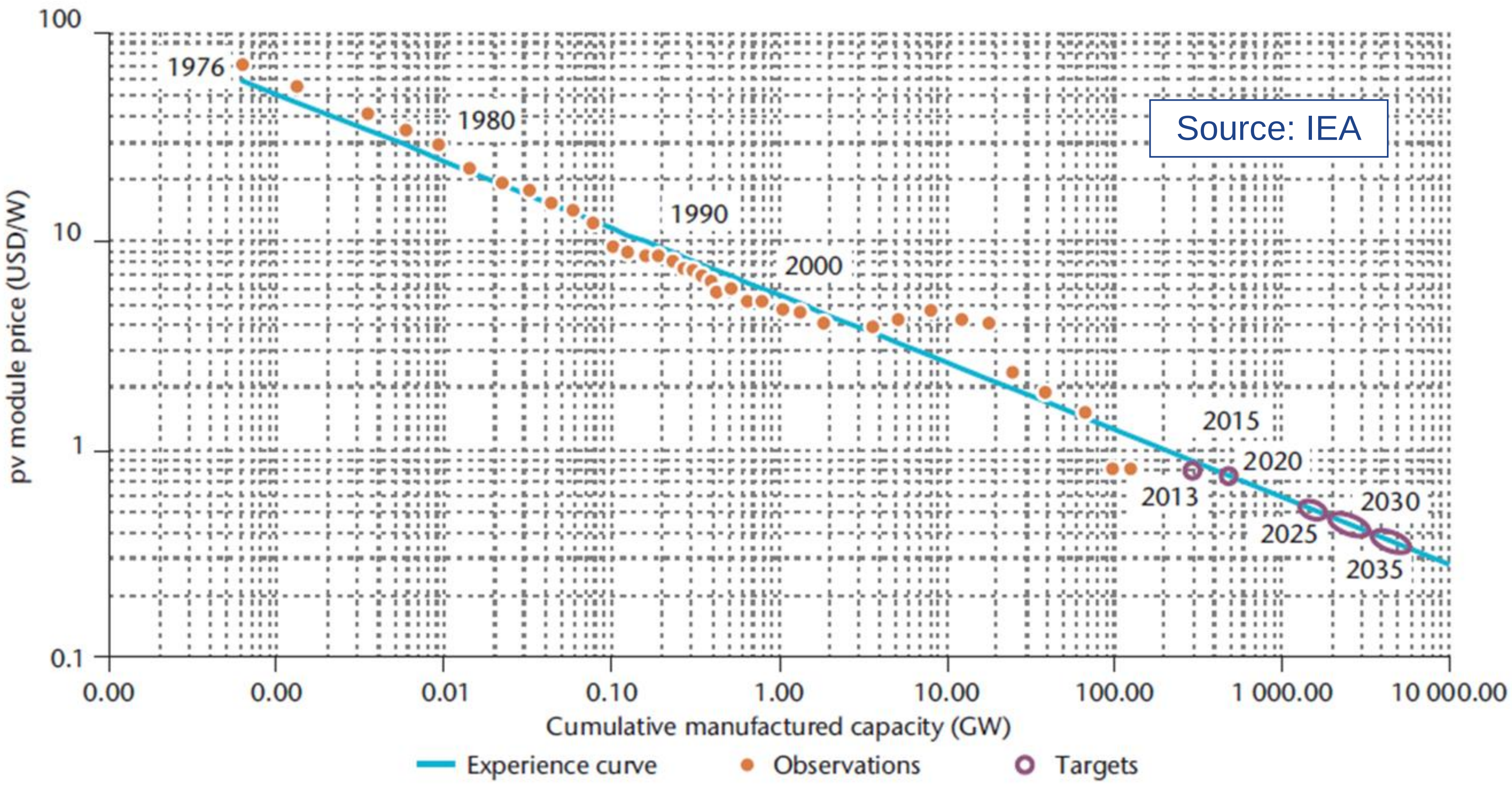
Motivation and Scope II – PV module price



Notes: Orange dots indicate past module prices; purple dots are expectations. The oval dots correspond to the deployment starting in 2025, comparing the 2DS (left end of oval) and 2DS hi-Ren (right end).

Motivation and Scope III – Objectives and models

Objectives

- From a policy-relevance perspective, explore different scenarios related to the possible future cost patterns of the solar PV technology
- From a modeling perspective, assess the responsiveness of models to changes in the cost data input

Participating models (→ Follow-up of the ADVANCE project on system integration modeling)

- IMAGE
- POLES

} Recursive dynamic partial equilibrium models

- REMIND
- WITCH

} Intertemporal optimal-growth general equilibrium models

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Learning-by-Doing and Floor Cost

Investment cost (Learning-by-Doing):

$$CC_t = CC_1 \left(\frac{K_t}{K_1}\right)^{-b}$$

Floor cost: hard bound

$$CC_t = max\left(FC, CC_1 \left(\frac{K_t}{K_1}\right)^{-b}\right)$$

Floor cost: soft bound (asymptotic)

$$CC_t = FC + (CC_1 - FC) \cdot \left(\frac{K_t}{K_1}\right)^{-b}$$

- CC_t = capital cost at time t
- CC_1 = initial capital cost
- K_t = global cumulative capacity at time t
- K_1 = global initial capacity
- b = a measure of the strength of the learning effect
  → LR = Learning Rate = cost decrease deriving from doubling the installed capacity = $-1 + 2^b$
- FC = floor cost

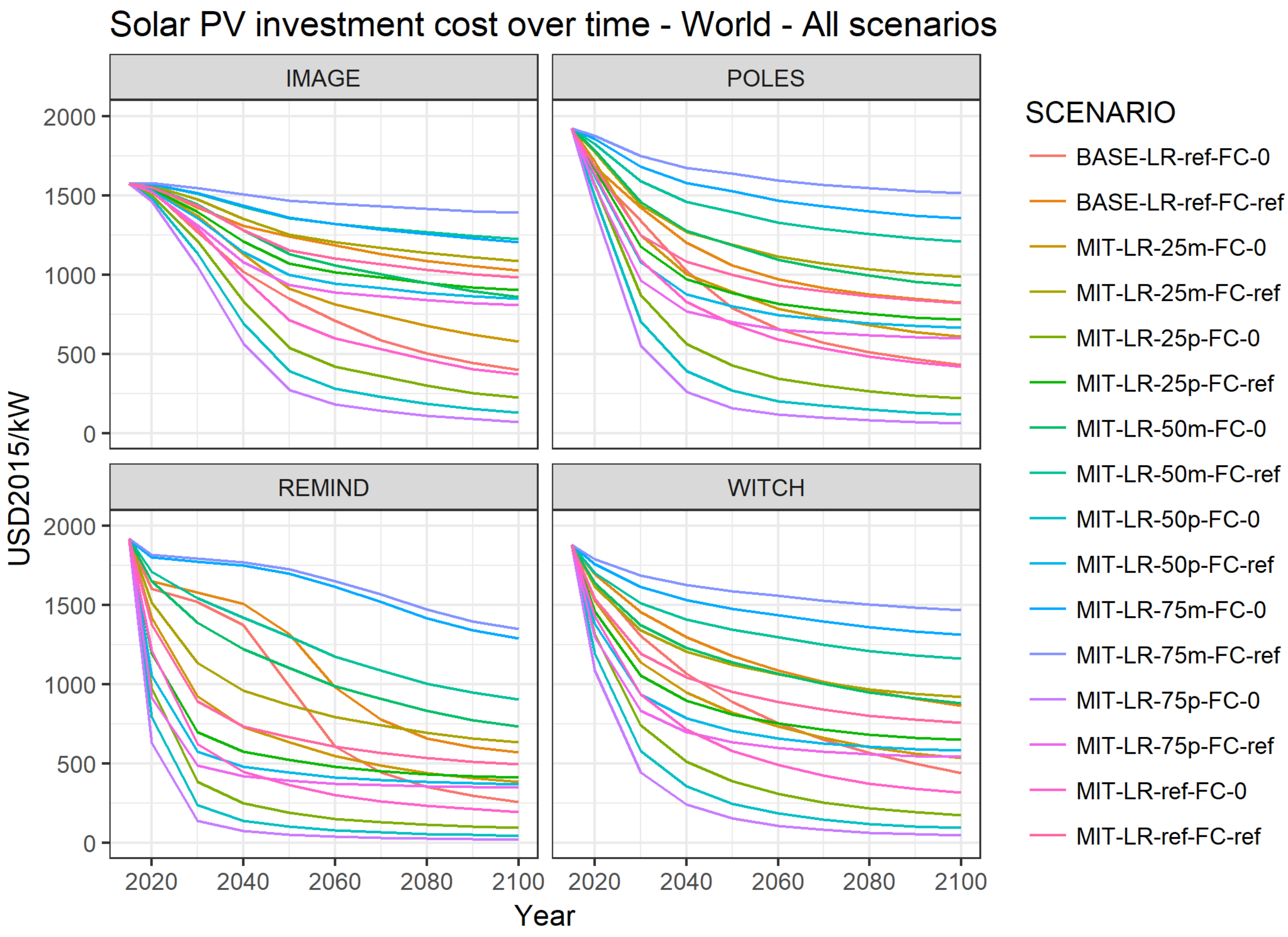
Scenario protocol

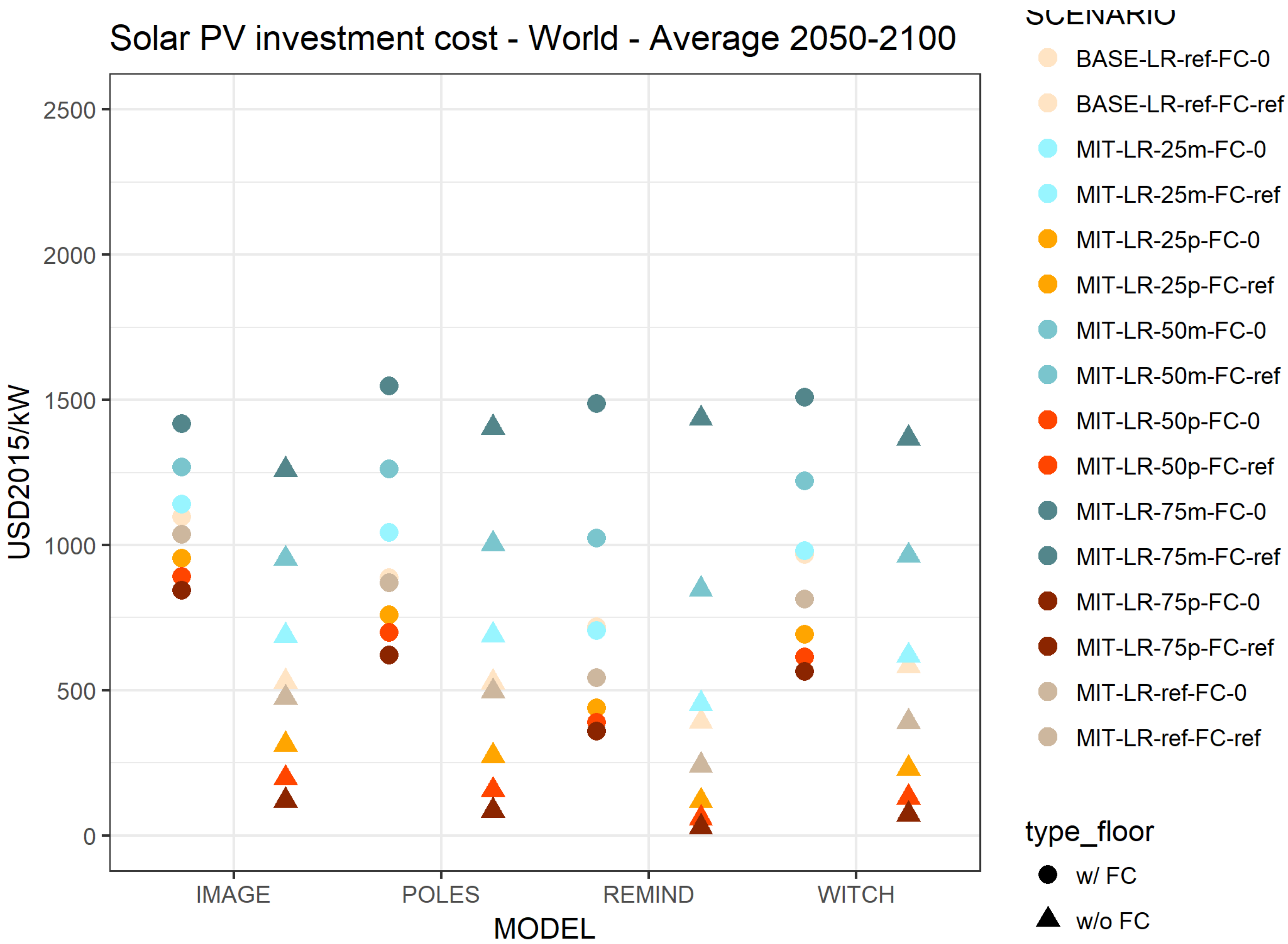
	Scenario Name	Policy	Learning Rate	Floor Cost
1	ADV4-PV-BASE-LR-ref-FC-ref	Baseline	Ref	Ref
2	ADV4-PV-BASE-LR-ref-FC-0	Baseline	Ref	0
3	ADV4-PV-MIT-LR-ref-FC-ref	Mitigation	Ref	Ref
4	ADV4-PV-MIT-LR-75p-FC-ref	Mitigation	+75%	Ref
5	ADV4-PV-MIT-LR-50p-FC-ref	Mitigation	+50%	Ref
6	ADV4-PV-MIT-LR-25p-FC-ref	Mitigation	+25%	Ref
7	ADV4-PV-MIT-LR-25m-FC-ref	Mitigation	-25%	Ref
8	ADV4-PV-MIT-LR-50m-FC-ref	Mitigation	-50%	Ref
9	ADV4-PV-MIT-LR-75m-FC-ref	Mitigation	-75%	Ref
10	ADV4-PV-MIT-LR-ref-FC-0	Mitigation	Ref	0
11	ADV4-PV-MIT-LR-75p-FC-0	Mitigation	+75%	0
12	ADV4-PV-MIT-LR-50p-FC-0	Mitigation	+50%	0
13	ADV4-PV-MIT-LR-25p-FC-0	Mitigation	+25%	0
14	ADV4-PV-MIT-LR-25m-FC-0	Mitigation	-25%	0
15	ADV4-PV-MIT-LR-50m-FC-0	Mitigation	-50%	0
16	ADV4-PV-MIT-LR-75m-FC-0	Mitigation	-75%	0

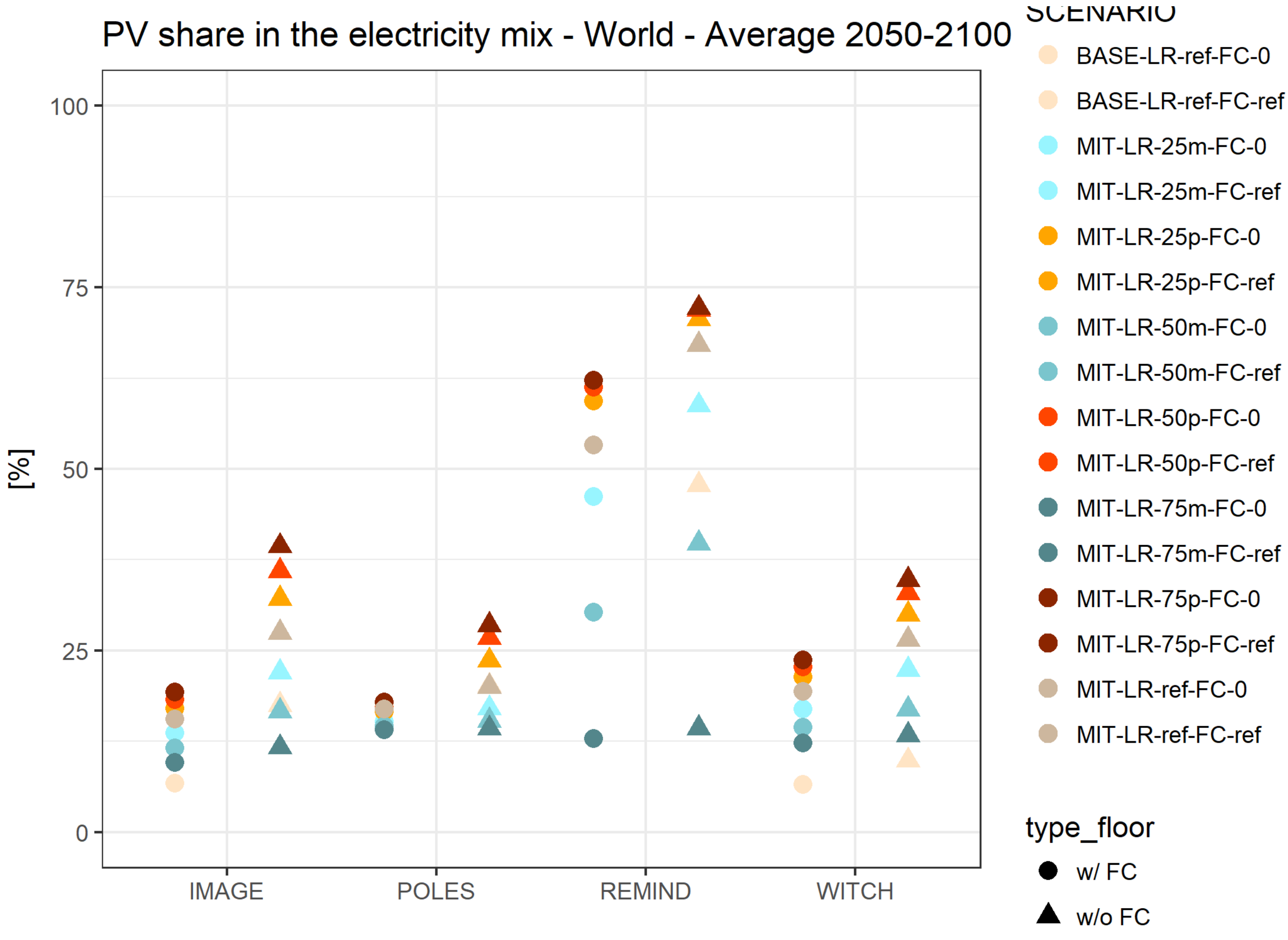
Mitigation → ctax | cumulative 1000 $GtCO_2$ in 2011-2100 in the Ref-Ref scenario → +2°C in 2100

Modeling assumptions (stocktaking)

	IMAGE	POLES	REMIND	WITCH
Cost calculation	Endogenous			
Type of endogenous modeling	One-factor learning curve (LbD)			
Regional differentiation	Yes, with (limited) spillover effects	No, only one global cost		
Type of floor cost	Soft bound (asymptotic)			
Plant depreciation	Linear	Linear	Concave	Exponential
Depreciation rate	0.1	0.04	-	0.044
Lifetime [years]	25	25	30	25
2015 investment cost [USD2015/kW]	1576	1924	1916	1879
Learning rate	20%	15%	20%	20%
Floor cost [USD2015/kW]	433	619	458	495


Solar PV investment cost over time - World - All scenarios
IMAGE
POLES
REMIND
WITCH
USD2015/kW
0
500
1000
1500
2000
2020
2040
2060
2080
2100
Year
SCENARIO
BASE-LR-ref-FC-0
BASE-LR-ref-FC-ref
MIT-LR-25m-FC-0
MIT-LR-25m-FC-ref
MIT-LR-25p-FC-0
MIT-LR-25p-FC-ref
MIT-LR-50m-FC-0
MIT-LR-50m-FC-ref
MIT-LR-50p-FC-0
MIT-LR-50p-FC-ref
MIT-LR-75m-FC-0
MIT-LR-75m-FC-ref
MIT-LR-75p-FC-0
MIT-LR-75p-FC-ref
MIT-LR-ref-FC-0
MIT-LR-ref-FC-ref


Solar PV investment cost - World - Average 2050-2100
USD2015/kW
2500
2000
1500
1000
500
0
IMAGE
POLES
REMIND
WITCH
MODEL
SCENARIO
BASE-LR-ref-FC-0
BASE-LR-ref-FC-ref
MIT-LR-25m-FC-0
MIT-LR-25m-FC-ref
MIT-LR-25p-FC-0
MIT-LR-25p-FC-ref
MIT-LR-50m-FC-0
MIT-LR-50m-FC-ref
MIT-LR-50p-FC-0
MIT-LR-50p-FC-ref
MIT-LR-75m-FC-0
MIT-LR-75m-FC-ref
MIT-LR-75p-FC-0
MIT-LR-75p-FC-ref
MIT-LR-ref-FC-0
MIT-LR-ref-FC-ref
type_floor
w/ FC
w/o FC



PV share in the electricity mix - World - Average 2050-2100
[%]
100
75
50
25
0
IMAGE
POLES
REMIND
WITCH
SCENARIO
BASE-LR-ref-FC-0
BASE-LR-ref-FC-ref
MIT-LR-25m-FC-0
MIT-LR-25m-FC-ref
MIT-LR-25p-FC-0
MIT-LR-25p-FC-ref
MIT-LR-50m-FC-0
MIT-LR-50m-FC-ref
MIT-LR-50p-FC-0
MIT-LR-50p-FC-ref
MIT-LR-75m-FC-0
MIT-LR-75m-FC-ref
MIT-LR-75p-FC-0
MIT-LR-75p-FC-ref
MIT-LR-ref-FC-0
MIT-LR-ref-FC-ref
type_floor
w/ FC
w/o FC

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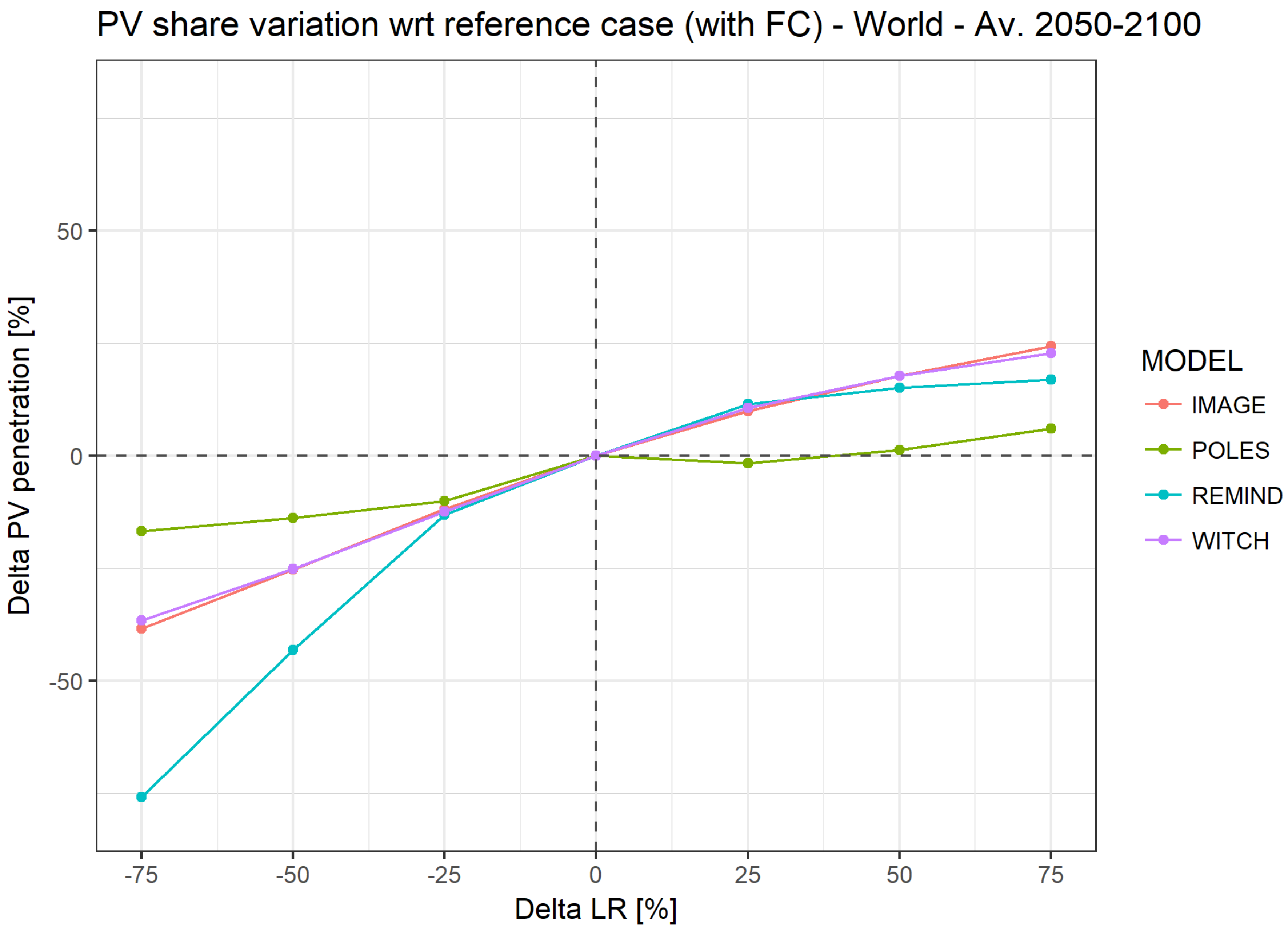
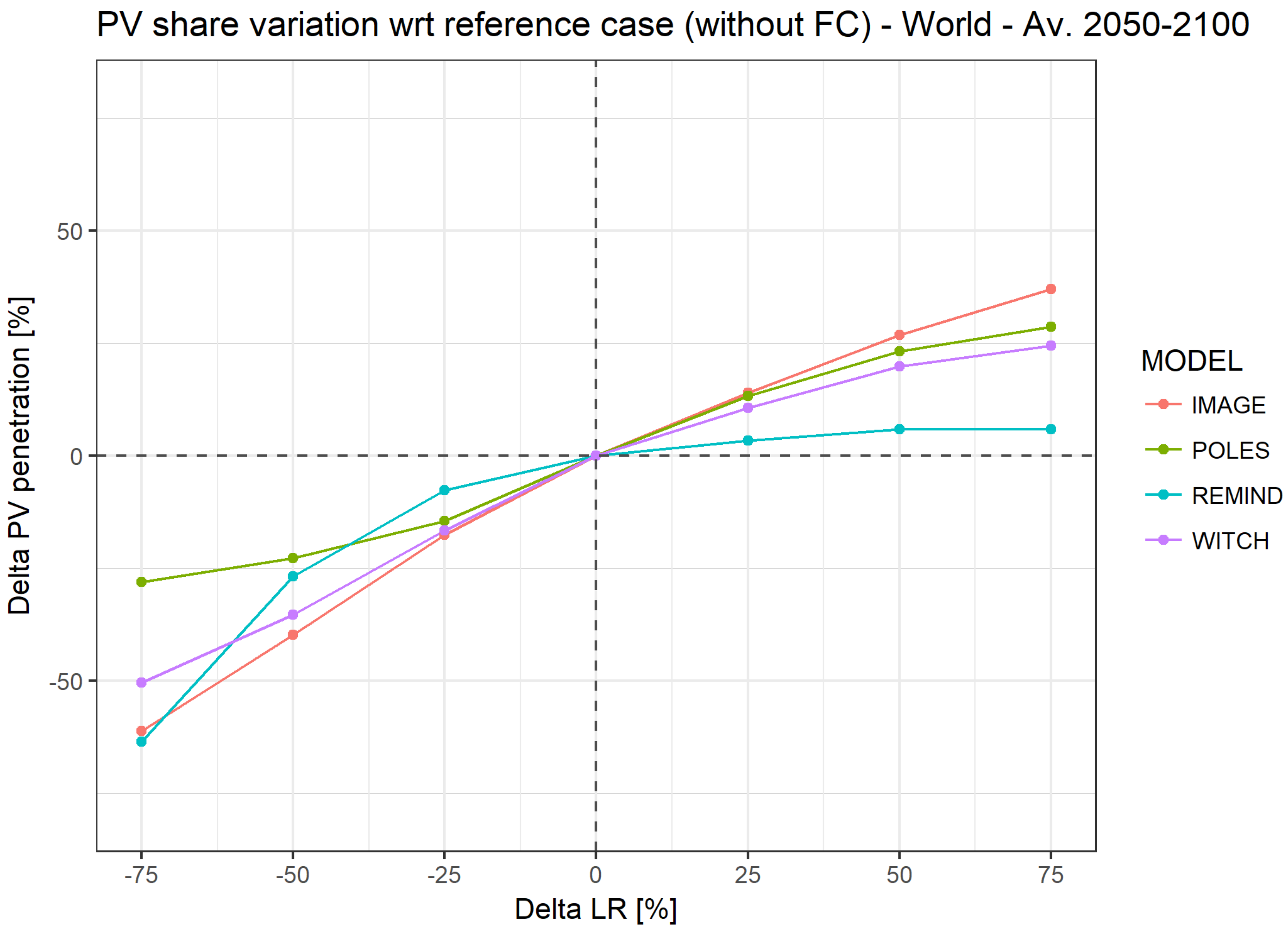
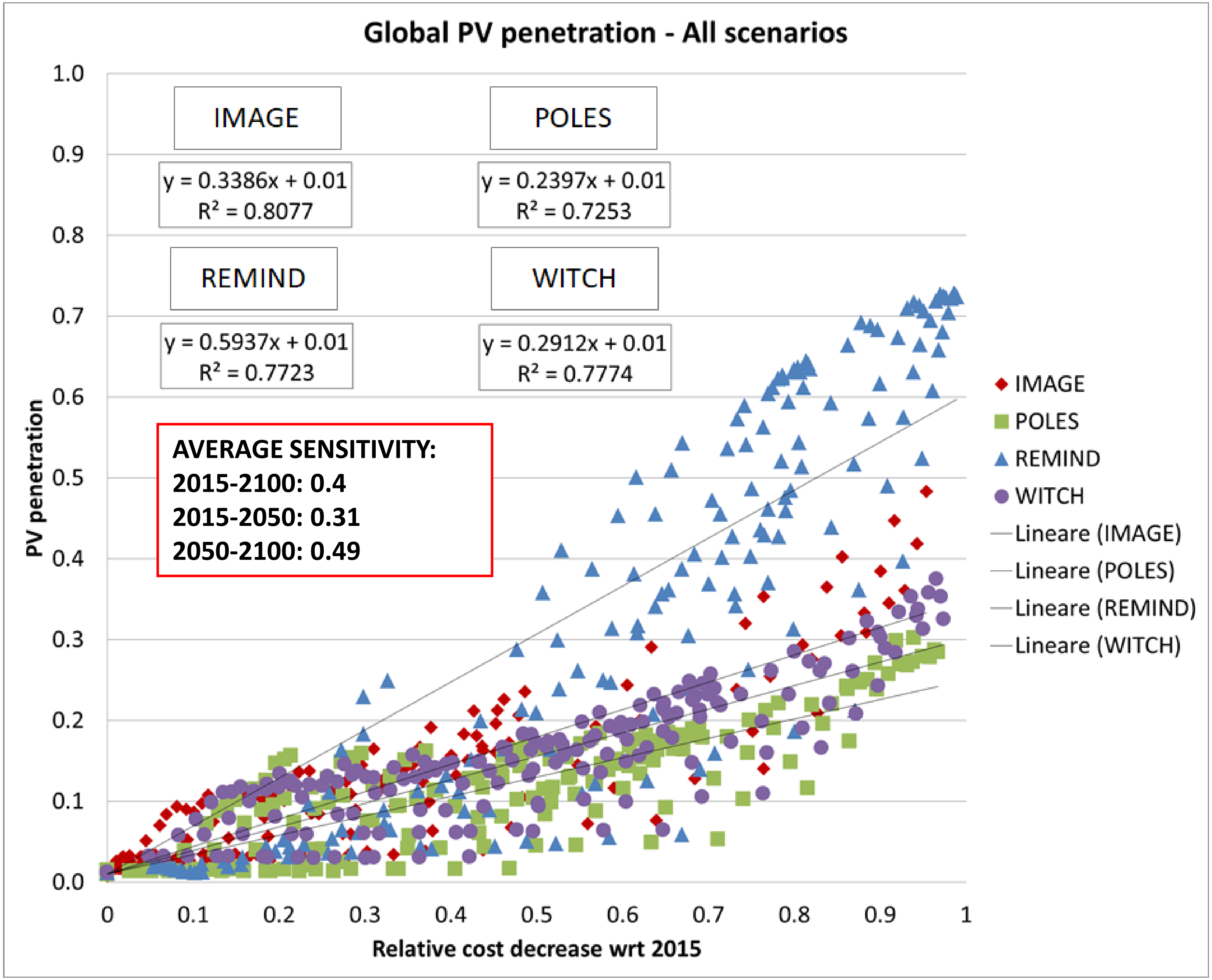
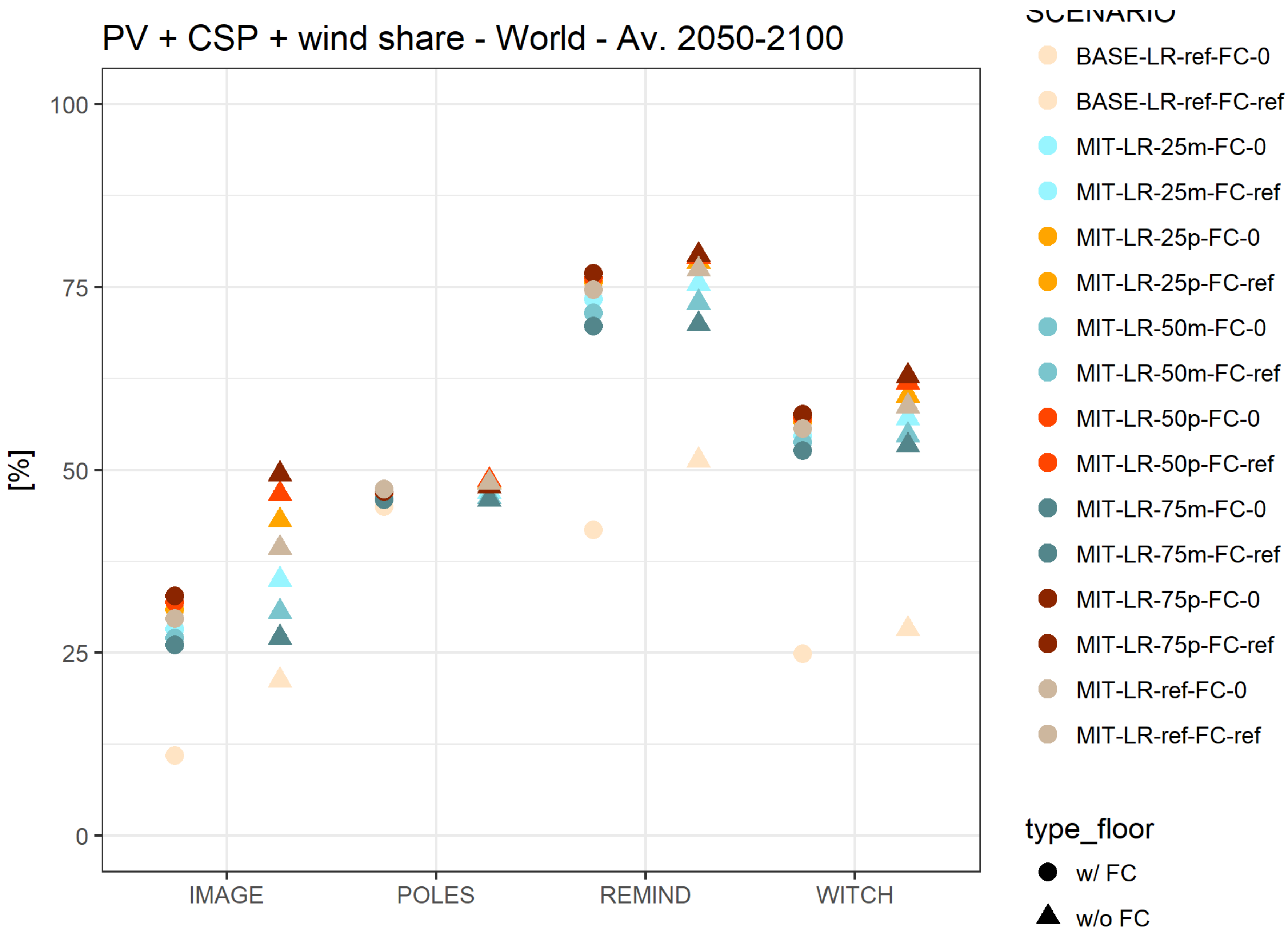

PV share variation wrt reference case (with FC) - World - Av. 2050-2100
Delta PV penetration [%]
50
0
-50
-75
-50
-25
0
25
50
75
Delta LR [%]
MODEL
IMAGE
POLES
REMIND
WITCH


PV share variation wrt reference case (without FC) - World - Av. 2050-2100
Delta PV penetration [%]
50
0
-50
-75
-50
-25
0
25
50
75
Delta LR [%]
MODEL
IMAGE
POLES
REMIND
WITCH



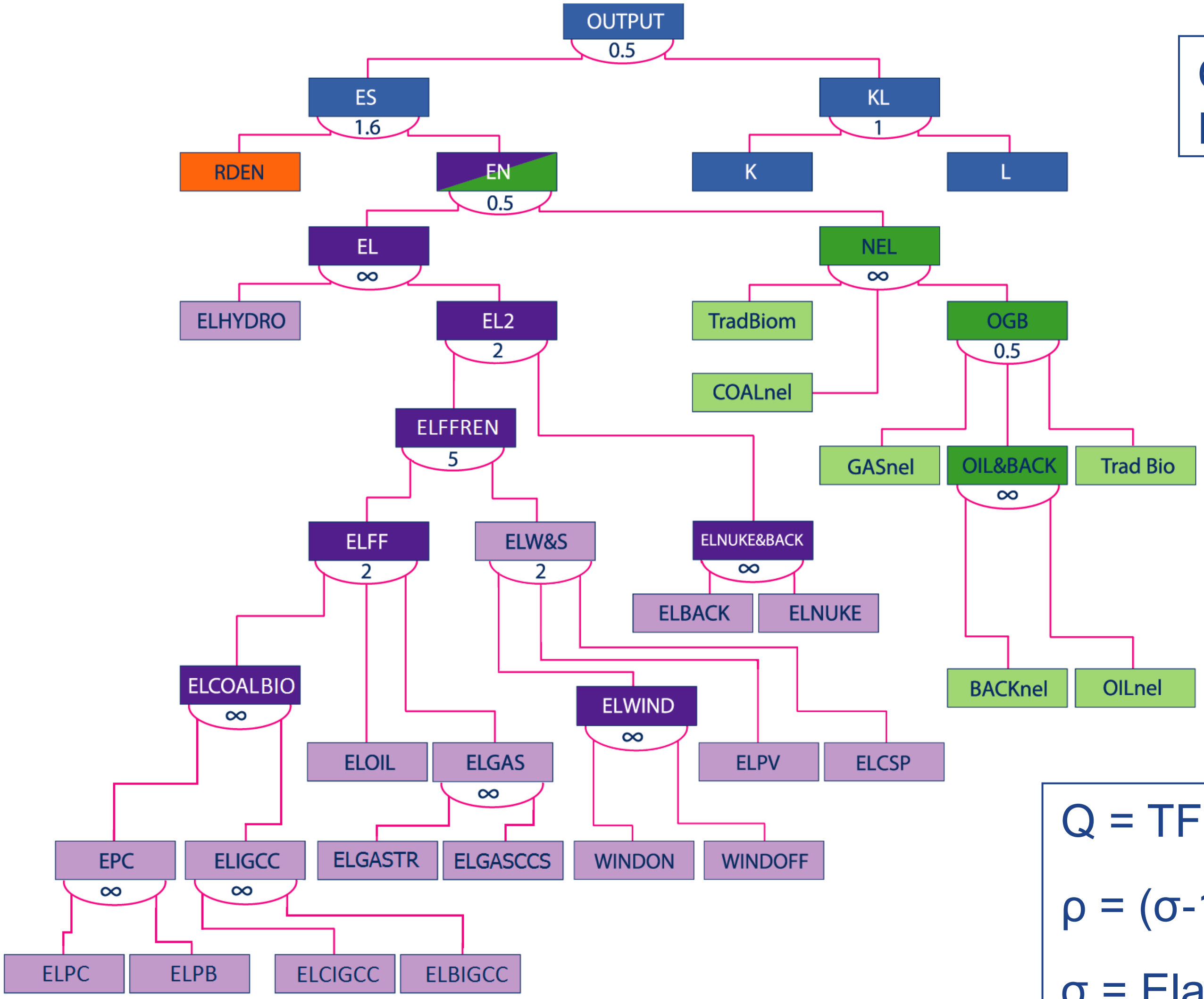
Global PV penetration - All scenarios
IMAGE
y = 0.3386x + 0.01
R² = 0.8077
POLES
y = 0.2397x + 0.01
R² = 0.7253
REMIND
y = 0.5937x + 0.01
R² = 0.7723
WITCH
y = 0.2912x + 0.01
R² = 0.7774
AVERAGE SENSITIVITY:
2015-2100: 0.4
2015-2050: 0.31
2050-2100: 0.49
PV penetration
Relative cost decrease wrt 2015
IMAGE
POLES
REMIND
WITCH
Lineare (IMAGE)
Lineare (POLES)
Lineare (REMIND)
Lineare (WITCH)


PV + CSP + wind share - World - Av. 2050-2100
100
75
50
25
0
[%]
IMAGE
POLES
REMIND
WITCH
SCENARIO
BASE-LR-ref-FC-0
BASE-LR-ref-FC-ref
MIT-LR-25m-FC-0
MIT-LR-25m-FC-ref
MIT-LR-25p-FC-0
MIT-LR-25p-FC-ref
MIT-LR-50m-FC-0
MIT-LR-50m-FC-ref
MIT-LR-50p-FC-0
MIT-LR-50p-FC-ref
MIT-LR-75m-FC-0
MIT-LR-75m-FC-ref
MIT-LR-75p-FC-0
MIT-LR-75p-FC-ref
MIT-LR-ref-FC-0
MIT-LR-ref-FC-ref
type_floor
w/ FC
w/o FC

Conclusions

- In the long run (2050-2100), global PV penetration spans a range of 10-72%, with a marked growth with respect to the current 1% in all scenarios and models.
- Models tend to show a limited sensitivity to PV penetration in their specific results. Sensitivity of PV penetration to capital cost reduction is averagely 0.4 across scenarios.
- Sensitivity to learning rates is not symmetric, being markedly higher for decreasing learning rates than for increasing learning rates.
- Models show a sort of “threshold” on which PV penetration tends to progressively collapse in the most favorable scenarios. This highlights the role of non-capital cost factors, especially system integration.
- Sensitivity to PV capital cost even diminishes when all Variable Renewable Energies (VREs, i.e. wind and solar CSP in addition to PV) are focused. This means that the higher/lower PV penetration related to its lower/higher capital cost mainly occurs to the detriment/benefit of wind and CSP.

WITCH: The CES structure



CES = Constant Elasticity of Substitution

$Q = TFP \cdot (a \cdot K^{\rho} + (1-a) \cdot L^{\rho})^{(1/\rho)}$

$\rho = (\sigma - 1) / \sigma$

σ = Elasticity of Substitution

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THANK YOU
FOR YOUR ATTENTION

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