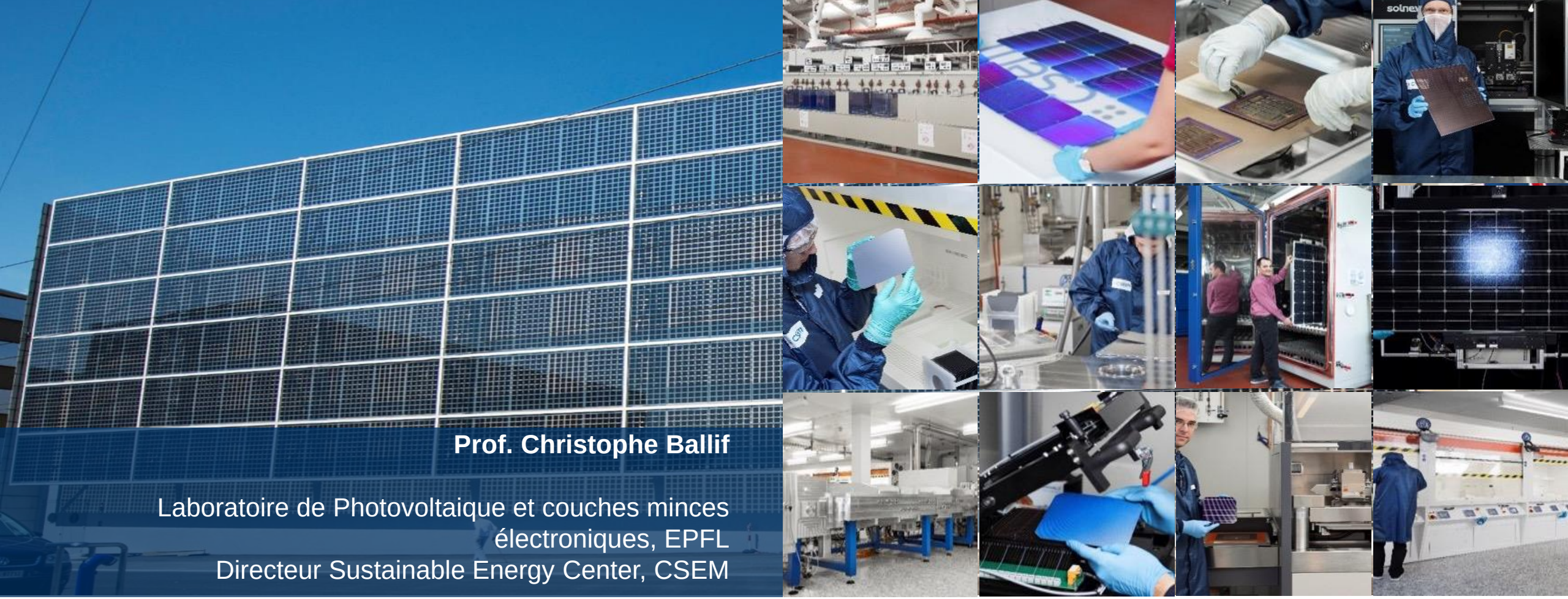

Prof. Christophe Ballif

Laboratoire de Photovoltaique et couches minces électroniques, EPFL
Directeur Sustainable Energy Center, CSEM

TECHNOLOGICAL AND MARKET PROGRESSES IN RENEWABLE, WIND AND EFFICIENCY: A SHORT TRAVEL BETWEEN SWITZERLAND AND THE WORLD

PHOTOVOLTAICS AND ENERGY SYSTEMS IN NEUCHÂTEL

CONTRACTS WITH OVER 40 COMPANIES ALONG THE CHAIN

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2800 M² OF INFRASTRUCTURE AND 120 PEOPLE.....

SMART GRID ACTIVITY PORTFOLIO

Networks

BKW ALPIQ

- Flexibility services from distributed ressources
- Inverter control
- Code generation for multi-vector optimization

Batteries

- Multi-service battery system
- Model-based state estimation

Renewables

Digital Energy

- Anomaly detection and diagnostics
- PV system modelling
- High-resolution PV forecasting

V-ZUG

Sontex your link to innovative metering

- ✓ Intelligent valves
- ✓ Improved COP of heat pumps
- ✓ Better distric heating

Buildings

SIG viteos toutes vos énergies

- Building model identification
- Prosumer optimization
- Individual tenant billing
- Need based ventilation

HOMSPHERE

Soleco AG Solar for economy & ecology

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PRODUCTION FORECAST AND PREDICTIVE MAINTENANCE FOR ENERGY ASSETS WITH CSEM AI

Digital Energy

Machine learning from Big data sets
and physical knowledge of systems

Applicability

- Wind
  Hydro
- Solar
- Heat pumps
- Cooling
- Batteries

Wind-Log™

BKW

digitel

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BATTERY RESEARCH ACTIVITIES AT CSEM BATTERY INNOVATION HUB

Coatings and Interfaces

- Thin-film coatings
- Wet coatings
- Interface functionalization

Solid-state electrolytes

- Polymer solid state
- Ceramic solid state
- Integration and stabilization in cell

Cell modelling

- SoX estimators based on EIS
- Validation vs. measurements
- Simulations

Cell/module testing

- Technological screening
- Ad-hoc testing protocols
- Second-life testing procedures

Post mortem analyses

- Opening
- Imaging
- Modelling

BMS prototyping

- CMS concept
- Active balancing
- EIS integration

System-level analyses

- Frequency regulation
- Power trading optimization
- V2G analysis

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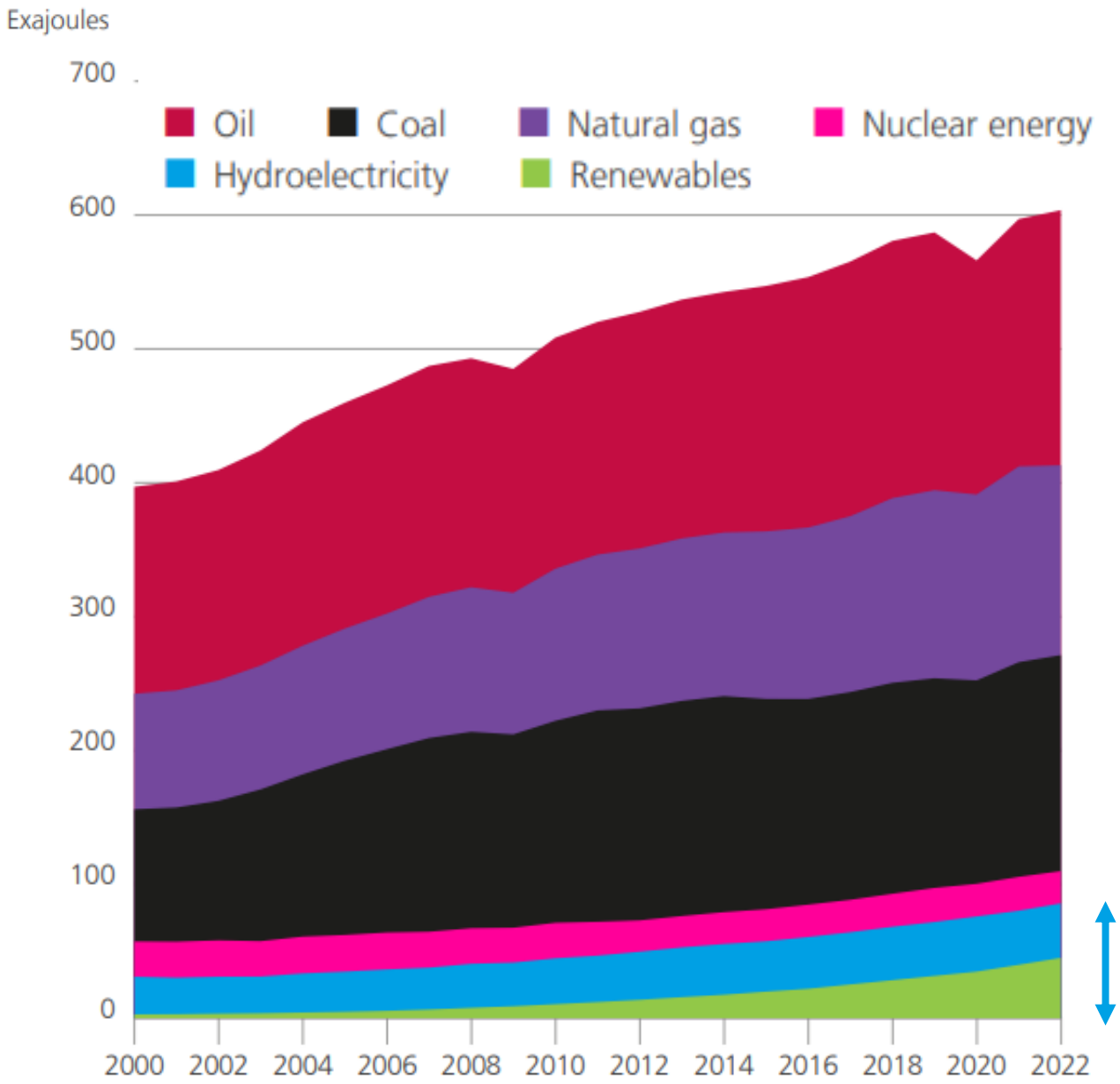
PRIMARY ENERGY CONSUMPTION



~ 168’000 TWh (CH 320 TWh)

2% annual growth
driven by **China and India**

Still 80% fossile fuel

*Electricity in kWh of biomass, hydro, solar, nuclear wind taken **multiplied by 2.5 to** be shown as primary energy source (BP)

CO2 free

Statistical review of world energy
World Energy Outlook 2023 (windows.net)

bp
iea

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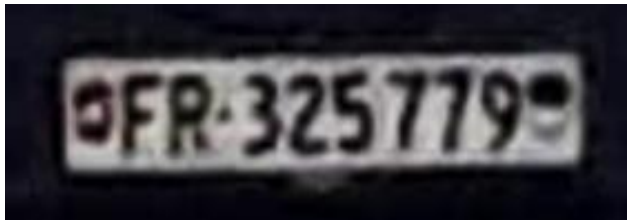
Fliegl
Fliegl
SAVARY TRANSPORT VESIN
avesco
MAKE DIESEL GREAT AGAIN


FR·3257779


COP28
DUBAI

QUICK RULE OF THUMBS ESTIMATIONS

- With a 1.5 % growth in primary* energy need (instead of 2%...)
  → **250’000 TWh** in 2050

- **Strong electrification** of heating/mobility + biomass +
  rest electricity for H_2
  → **100’000 TWh** electrical production by 2050

3x more electricity by 2050, while stopping coal oil and in large part gas

Today:
28’000 TWh

In 2022*:

- hydro ~ 4300 TWh
- Nuclear 2600 TWh
- wind 2100 TWh
- Solar 1300 TWh

*according to BP subsitution technique technique

*Global Electricity Review 2023 | Ember (ember-climate.org)

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4 MAJOR OPTIONS FOR 100‘000 TWh ANNUAL ELECTRICITY PRODUCTION

1GW Nuclear → 8 TWh/year (8000 hours)

1GW solar → 1-2 TWh/year (1000-2000 hours)

1GW wind → 2-4 TWh/year (2000-4000 hours)

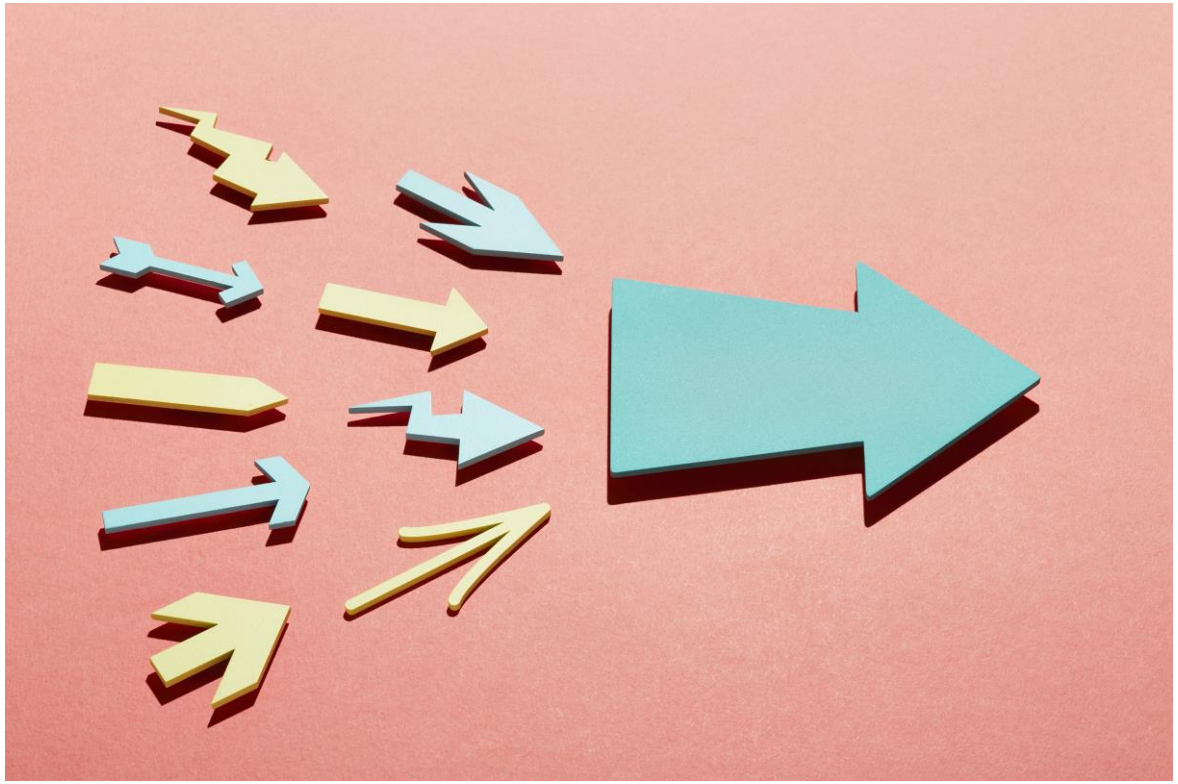
Which can be combined.....

a. e.g. 40‘000 GW of Solar and 15‘000 GW of Wind (+ Hydro + Biomass)

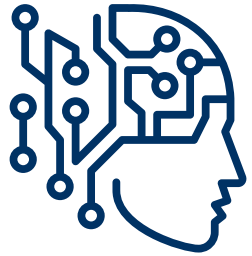
b. 13’000 x 1 GW nuclear power plants

c. Carbon sequestration

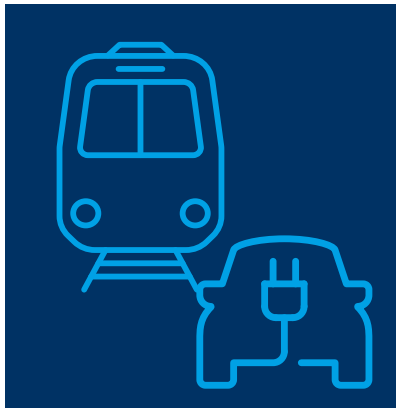
d. Don’t care (or too late…)



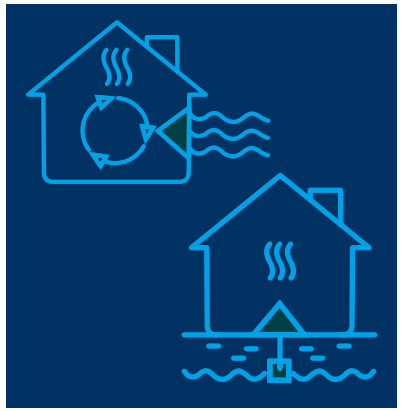
MAJOR TECHNOLGICAL ROUTES FOR THE ENERGY TRANSITION



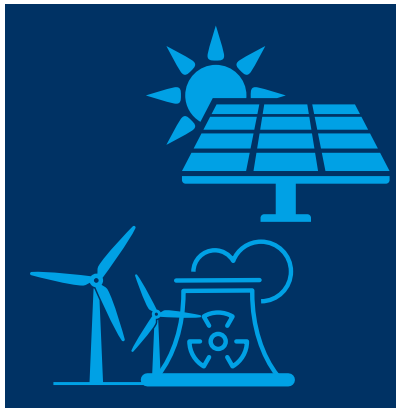
Flexibility and **intelligence (e.g. good forecast)**



Public transport or **electric cars + batteries**



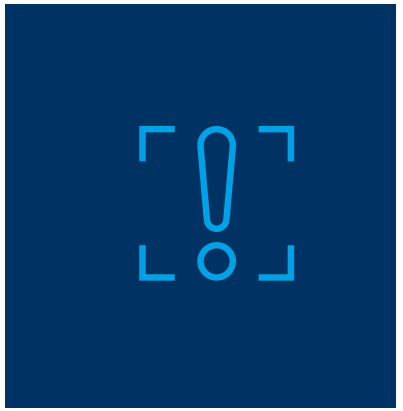
Heat pumps (air and geothermal)



Solar, Hydro, **Wind, Biomass** (Nuclear)

Insulation, efficiencey

Tracking losses



+ many small (but important)

+ H2 ….

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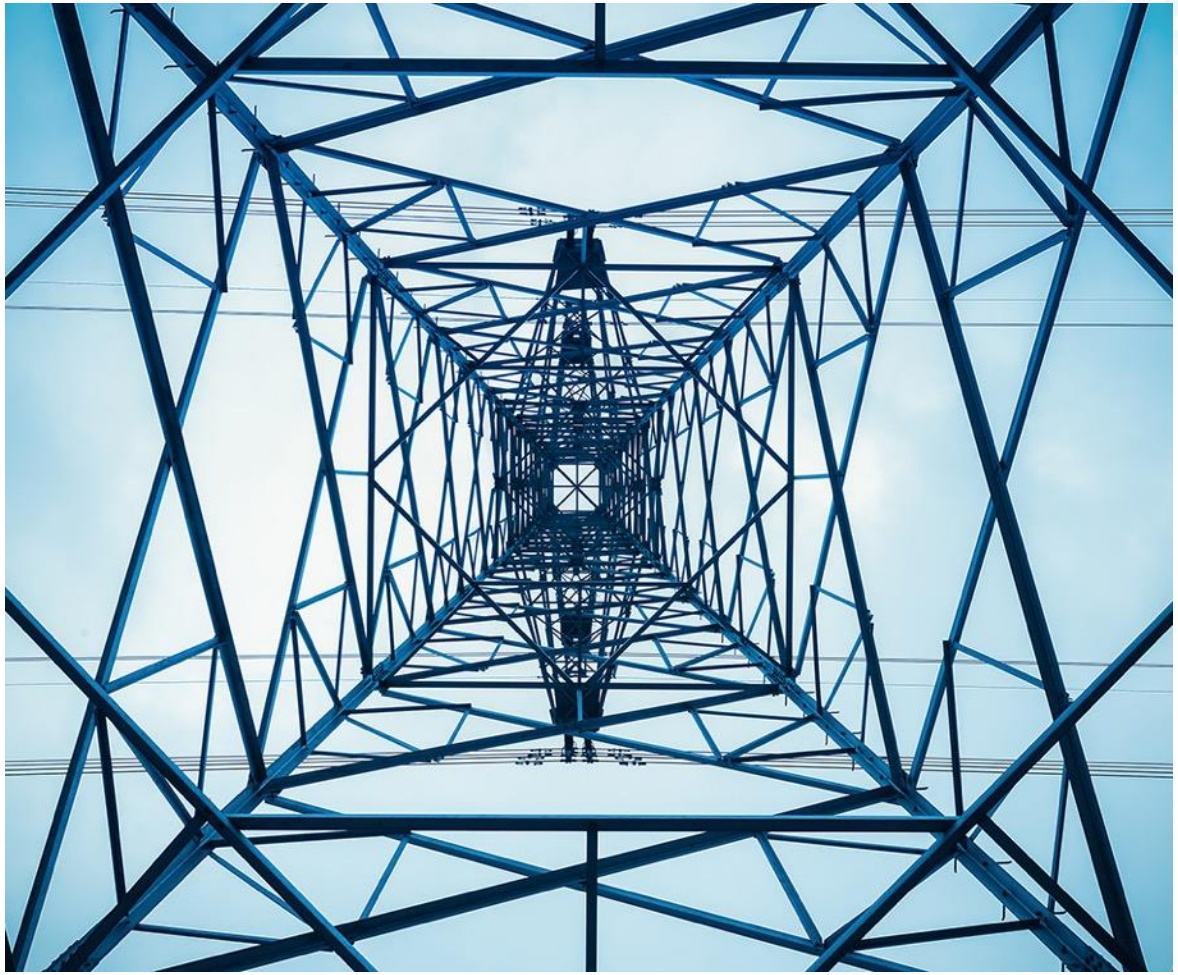
Michael Child, C. Breyer, et al. Renewable Energy 139 (2019) 80–101

With massive wind and solar, European grid can be balanced on an hourly/weekly basis but short-term storage (batteries mostly and pump storage) required



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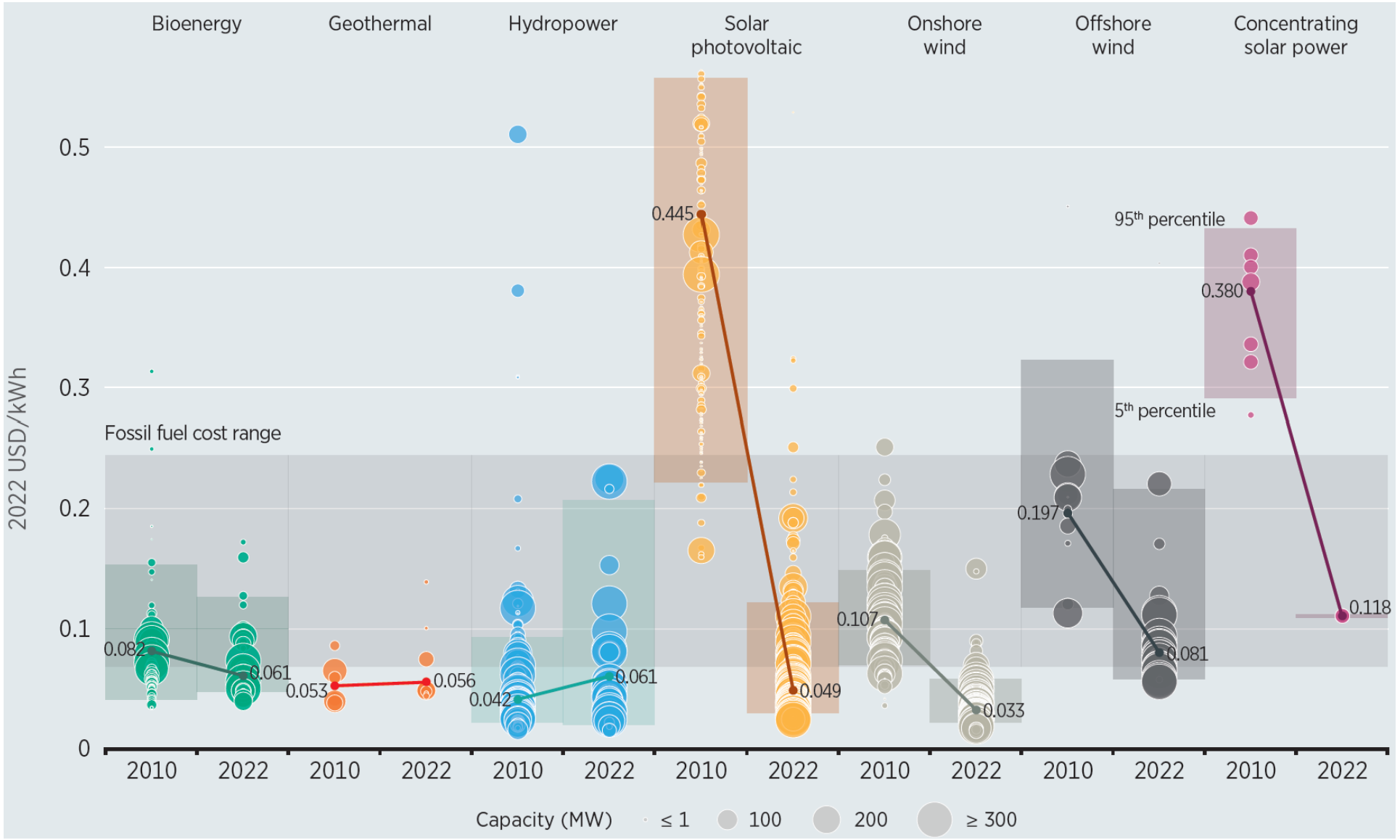
COST OF ELECTRICITY

Global LCOEs from newly commissioned, utility-scale renewable power generation technologies, 2010-2020

Drop in generation costs of renewables from 2010 to 2022



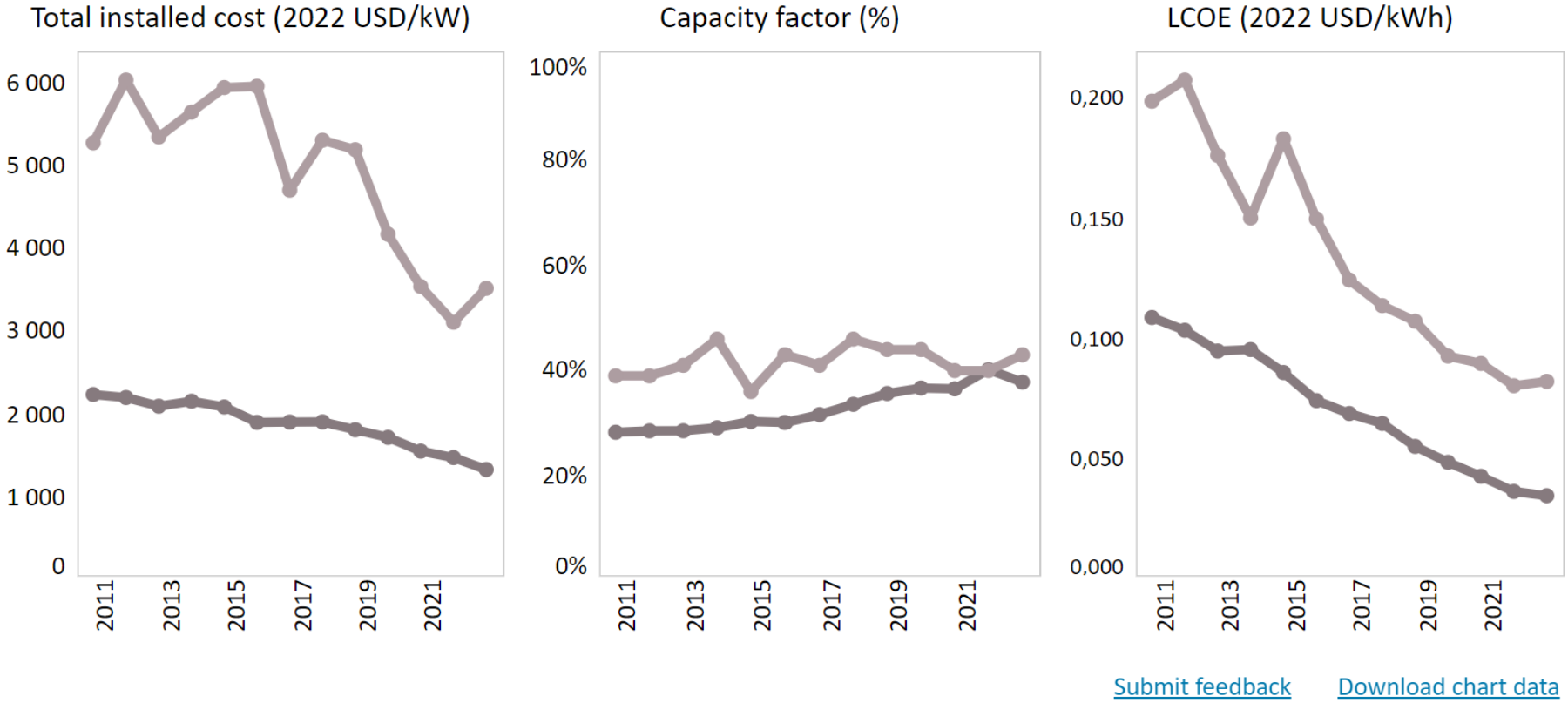
FOSSILE FUEL COST RANGE 2022

In ten years Wind and solar large parks direct electrecity costs well below fossile fuels

Source:
IRENA report «Renewable power generation costs in 2022"

csem

Wind energy



On-shore EU wind cost decrease (1.3 M$/MW)
Increased capacity factor with larger turbines
Average LCOE ~ 4 cts/kWh
(best place in the 2-3cts/kWh)

OFF-shore wind
System cost decrease (3.2 M$/MW)
Slightly higher capacity factor
Average LCOE ~ 8-9 cts/kWh
(best place in the 6cts/kWh)

https://www.irena.org/Statistics/View-Data-by-Topic/Costs/Global-Trends

Increased in Capacity factors thanks to large windmills

Not for Switzerland… but impressive size

20-MW turbine in Hainan,

26-MW Turbine offshore, 310 diameter !

PV ? MANY IMPROVEMENTS! AND MORE DURABLE

1st major improvement

Siemens silicon recrystallation process 200 kWh/kg of Si in 2000!!!

Today:

Can make 10 tons of silicon per run,
tubular filaments, cold reflected coated walls.

Only 40-45 kWh/kg.

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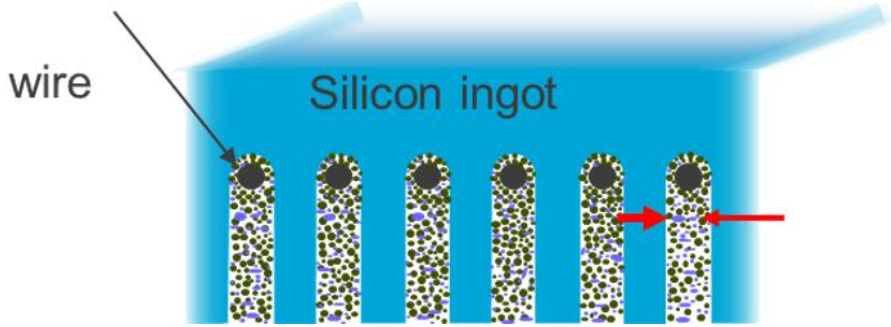
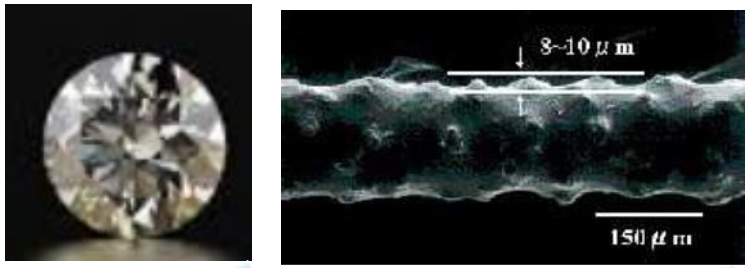
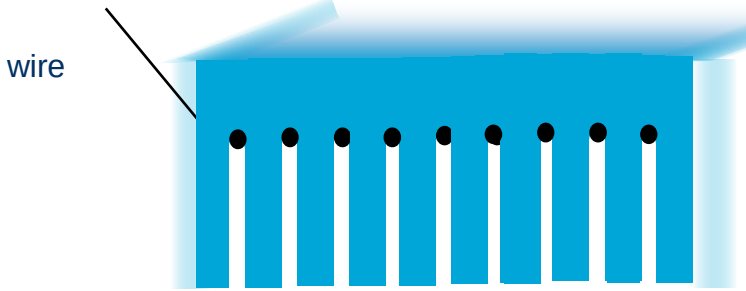
DURABILITY OF PV

2nd major improvement

Wafer sawing







Yesterday, multi-wire sawing, SiC particles
→ 200 microns lost Si

Today, diamond wires for mono c-S
→ 50 microns lost Si (36 microns wire)
→ 80 % more wafers than 5 years ago!

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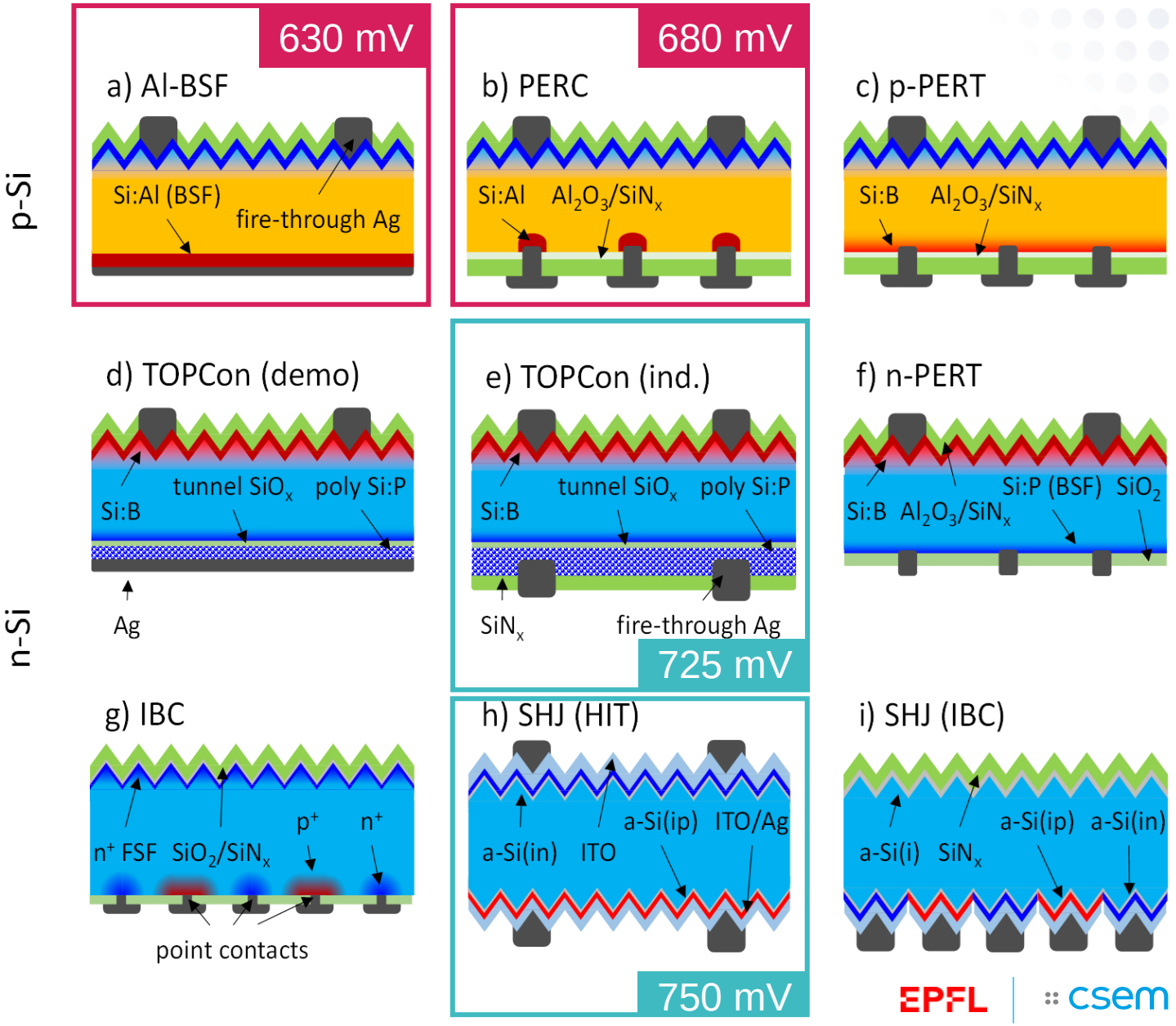
DURABILITY OF PV

3rd major improvement technologies

The various types of silicon technologies:

More and more Voltage !!



Ballif/Haug et al. Nat. Rev Materials 2022

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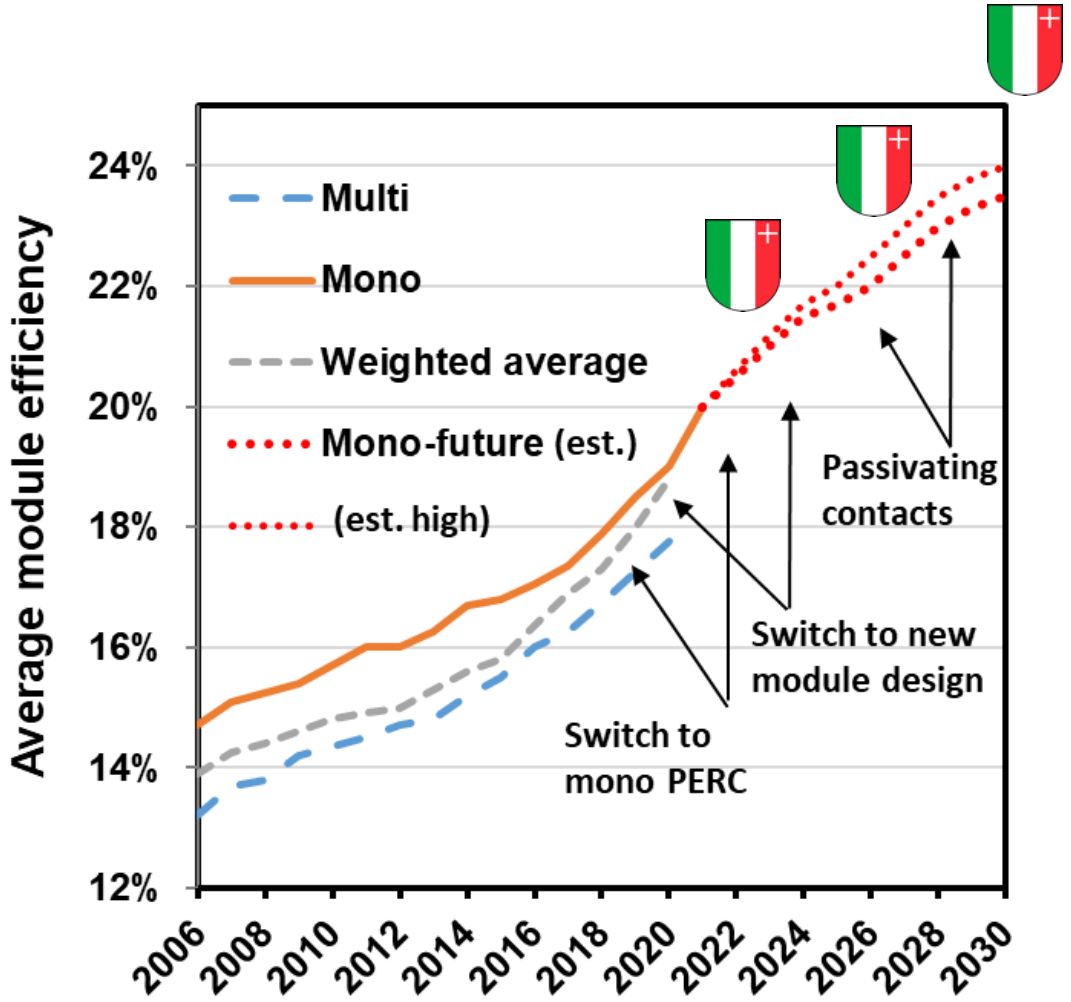
PERMANENT INCREASE IN THE MODULE EFFICIENCY



- 0.4-0.5% gain per year
- Todays average cells at 22.5-23.5%, modules at 20.5-21% average
- Efficiency will further increase → practical limit at 24–25%

Reduces all other material costs/usage per W

Haug, Ballif et all. Nat. Rev. Materials 2022

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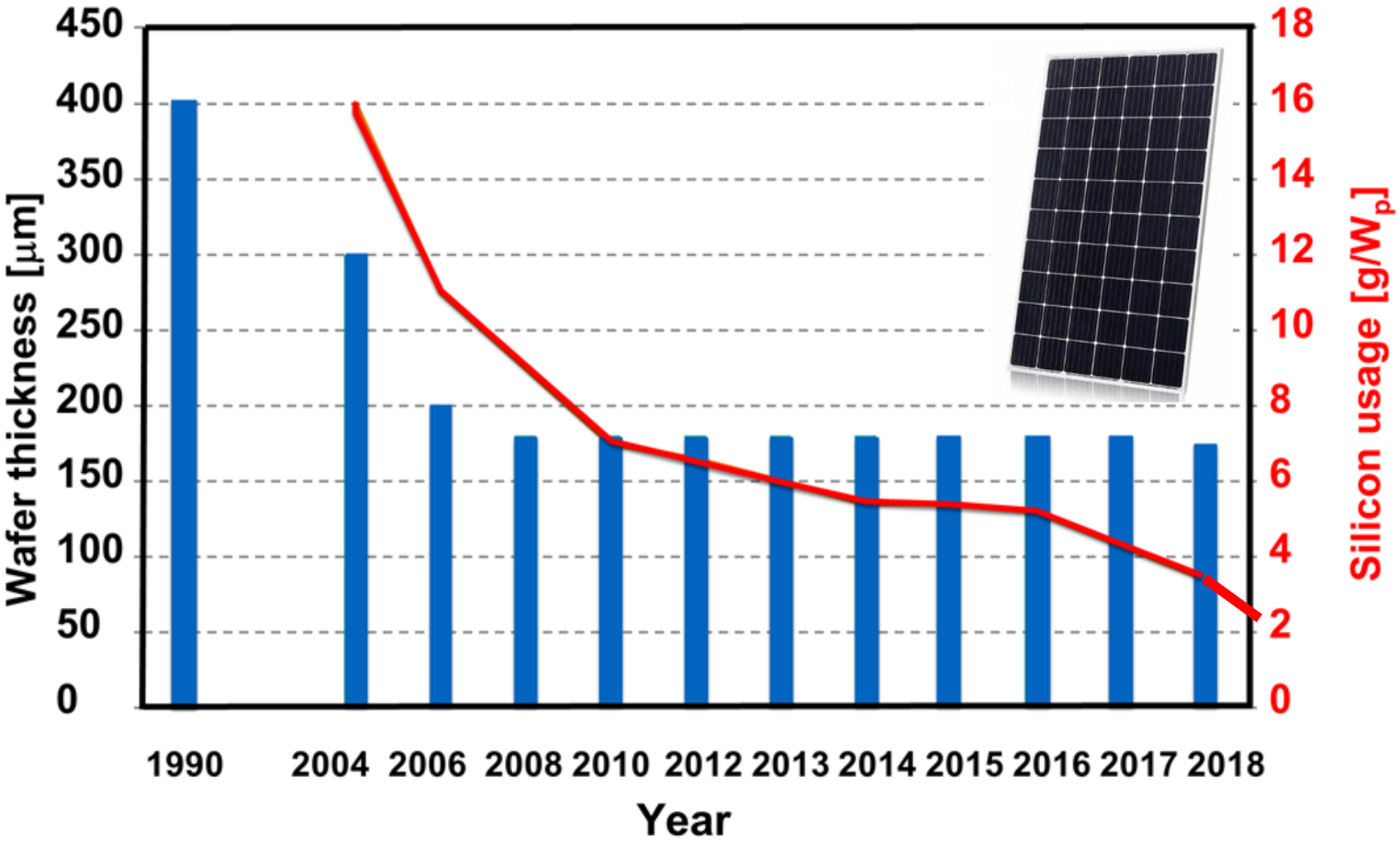
PURIFIED SILICON USAGE PER WATT FOR SILICON PV MODULES



Haug, Ballif et all. Nat. Rev. Materials 2022, source Fraunhofer ISE, PSE)

From 17 to 2 g/W in 2022 in 20 years thanks to:

- Improved processes (poly-si)
- Diamond wire sawing
- Thinner wafers
- Efficiency increase

- Energy paybacktime below 1 year, lower CO2 content

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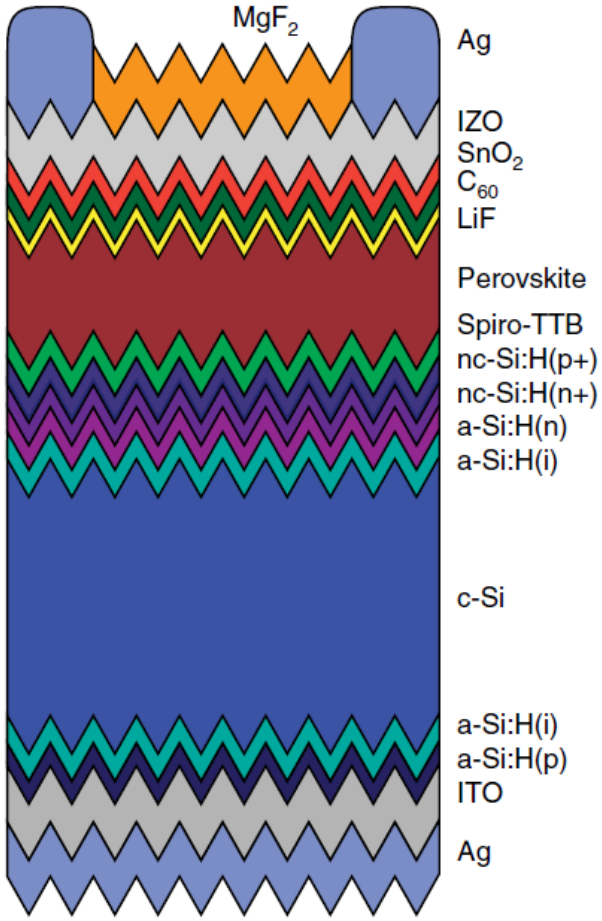
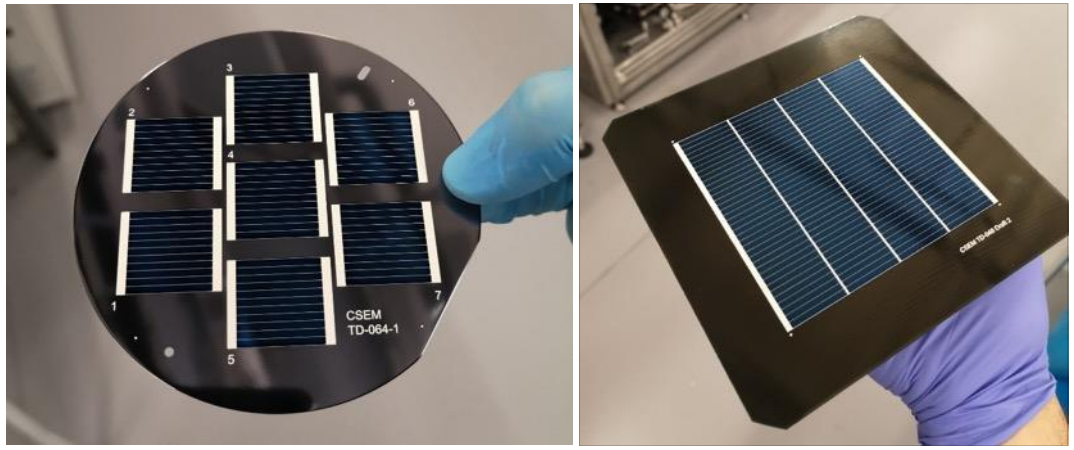
CELLS ABOVE 30%? FOR THE FIRST TIME PEROVSKITE/SILICON TANDEM SOLAR CELL BY EPFL/CSEM



Sahli et al. Nature materials 2018

EPFL PV-lab/CSEM
first time WR > 30%
Certified > 31.3%*



CSEM
Upscaling ongoing
And 29.6% certified on 25 cm^2

Xin Yu Chin et al. Science, 2023

Turkey et al. Artuk et al.

BRIDGE

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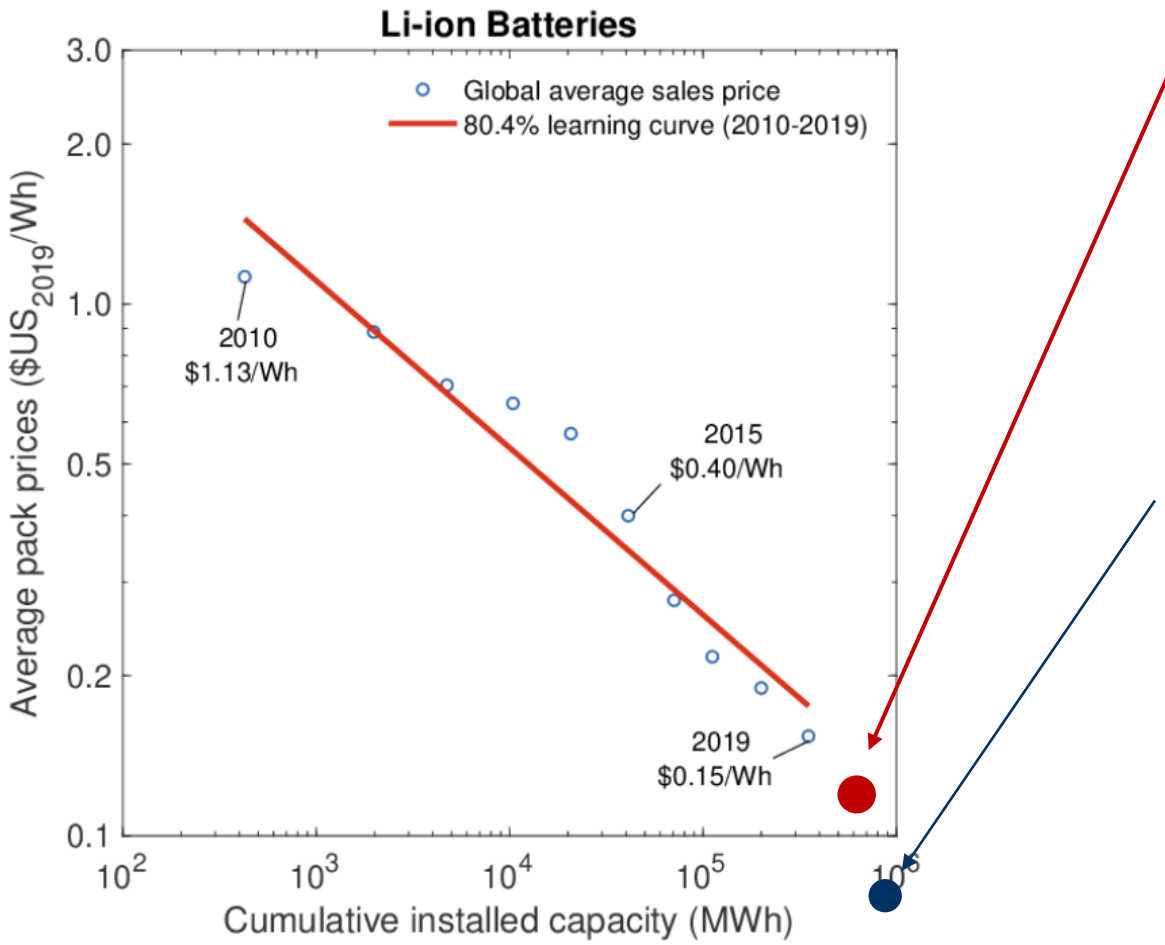
STORAGE STIMULATED BY THE AUTOMOTIVE MARKET

Automotive Battery learning curve



Cost Dynamics of Clean Energy Technologies, Glenk et al.

Today automotive battery pack at 100-120 $ /kWh

“We expect the price of an average battery pack to $62/kWh by 2030

Ultra-fast learning curve, as for PV

Usable for stationnary storage

EPFL | csem

510 GW IN 2023 NEW INSTALLATION OF RENEWABLES…. INCLUDING 375 GW SOLAR AND 107 GW OF WIND

SO WE INSTALLED THE EQUIVALENT OF 100 TO 110 NUCLEAR POWER PLANT OF 1 GW EACH RUNNING 100% OF THE TIME

BUT THE WORLD NEEDS TO INSTAL 4-5X MORE PER YEAR TO REACH NET ZERO BY 2050

Mitigating CO_2 Emissions and Scenarios

Energy transition will require even huge amount of solar panels, batteries, windturbines, electric cars, electrolysers …..

And huge investiment in manufacturing plants,…

e.g. > 120-150 billions $ to make the production lines (equipements and building) to make and extra 1000 GW of PV

Prof. Dr. Christophe Ballif

The Role of China

- Massive investment (>> 200 Billions in production assets) during COVID times: in PV, batteries and Wind manufacturing

(+ in electric cars)

In PV close to 1400 GW of production capacity are ready
(enough for ideal scenario….)

For batteries, soon capacity **for 4800 GWh** by end 2025

(enough fror **100 millions** car per year equivalent)

Ultra-harsh internal competition,
Overcapacity (factor 2.5 to 3 for 2024)

- PV panels at 12cts/W
- Inverters at 3cts/W
- Battery cell at down to 55$/kWh !
- Windturbine at 40 cts/W
- Electrolysers systems at 30 cts/W
- Ultra-low cost heat pumps

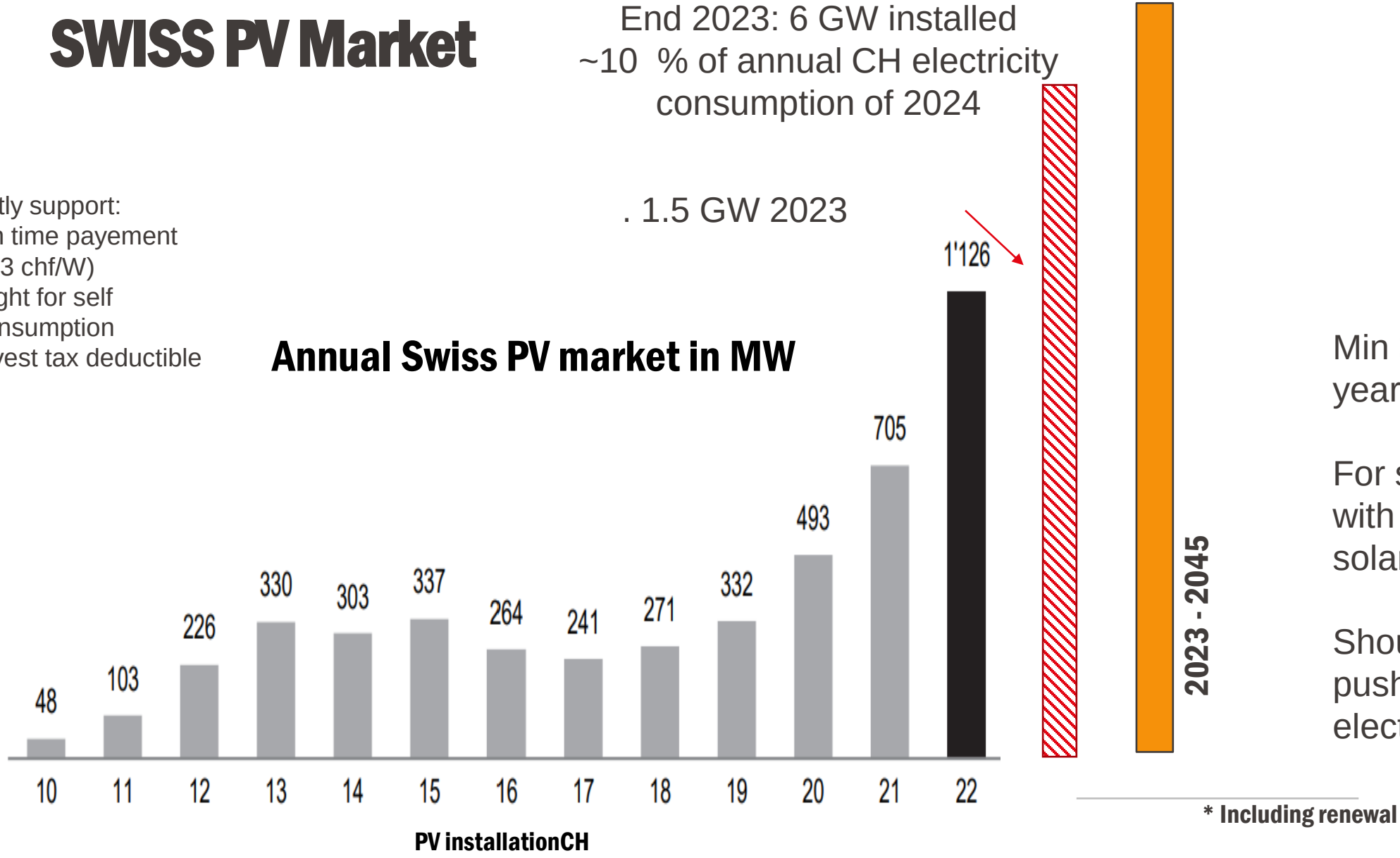
Prof. Dr. Christophe Ballif

SWISS PV Market

End 2023: 6 GW installed
~10 % of annual CH electricity consumption of 2024

. 1.5 GW 2023

Currently support:
- On time payement (0.3 chf/W)
- Right for self consumption
- Invest tax deductible



Min > 1.7 GW year

For scenarios with 50 GW solar….

Should be pushed with new electricity law !

Orders of magnitudes starts to be ok !

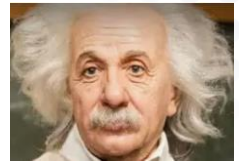
Source: Swissolar/internal data

HOW PV HELPS SOLVE THE «WINTER PROBLEM» IN CH –

- **Put more quickly more photovoltaics everywhere and curtail (easy)**
- Put more PV on facades and in the Alps (less easy but useful)
- Increase some dams height/new dams, optimise for Swiss autarcy not costs
- More wind for winter production/ reduce time to construction and opposition
- Biomass/biofuel, wastes, wood, for winter
- In 2040, hydrogen import (partially through NH3 systems ?) or closed loop CO_2/CH_4..
- LOHC)

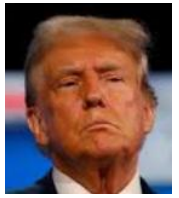
* If no wind, clear need for important electricity/energy import for winter time

BUT MANY CHALLENGES AHEAD IN CH



Ideal scenario

- Intelligence and anticipate
- Control all heat pumps
- Car charging bi-directional
- Curtail PV



Reality

- Some pockets of local optimisations
- No anticipation
- Uncontrolled management
- DSO will have to install many more batteries faster
- Forced Curtailement of PV

Forecast of demand and production imprecise

Limited system flexibility

From heat pump and mobility

csem

THE CASE FOR HEAT PUMPS

EPFL Thèse n°7926

Frédéric Louis-Pierre Raphaël Marie AMBLARD

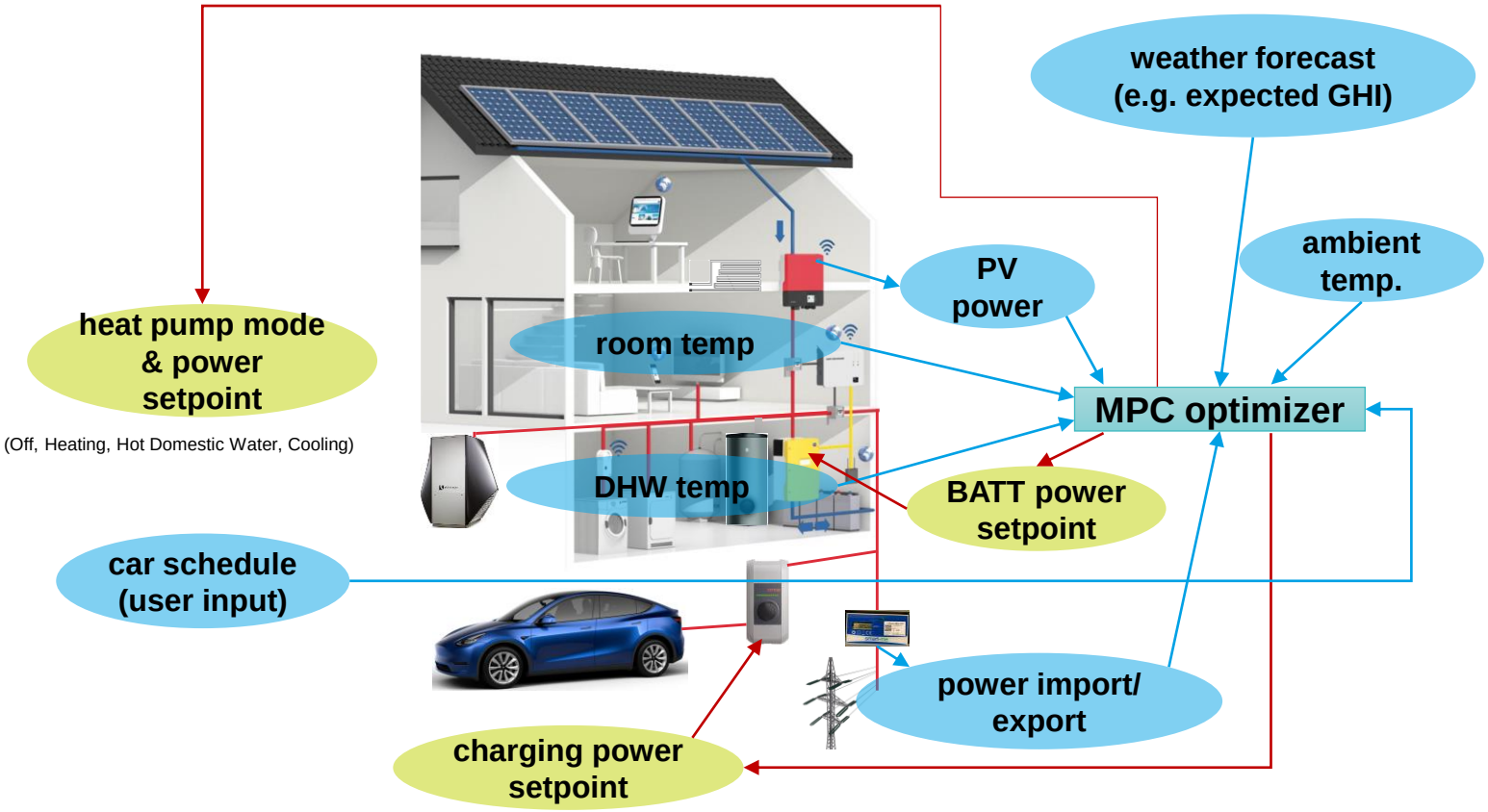
Reliability and Performance of Model Predictive Control for Demand Response with Residential Heat Pumps

Présentée le 8 janvier 2021

However, these industry standards do not translate well in the age of the Internet of Things (IoT) and for use with DR. Proprietary standards, and the lack of conversion interfaces, are the biggest technical obstacles preventing devices like heat pumps from being used for DR services.

Finally, there needs to be concerted effort and collaboration between the market actors, heat pump manufacturers and the designers of the latest machine learning and control algorithms. There is a major gap between the solutions presented in research papers and their implementation on real systems. Software and hardware that are flexible enough to adapt

NRG Maestro Optimizer



Solutions by

Soleco AG
Solar for economy & ecology

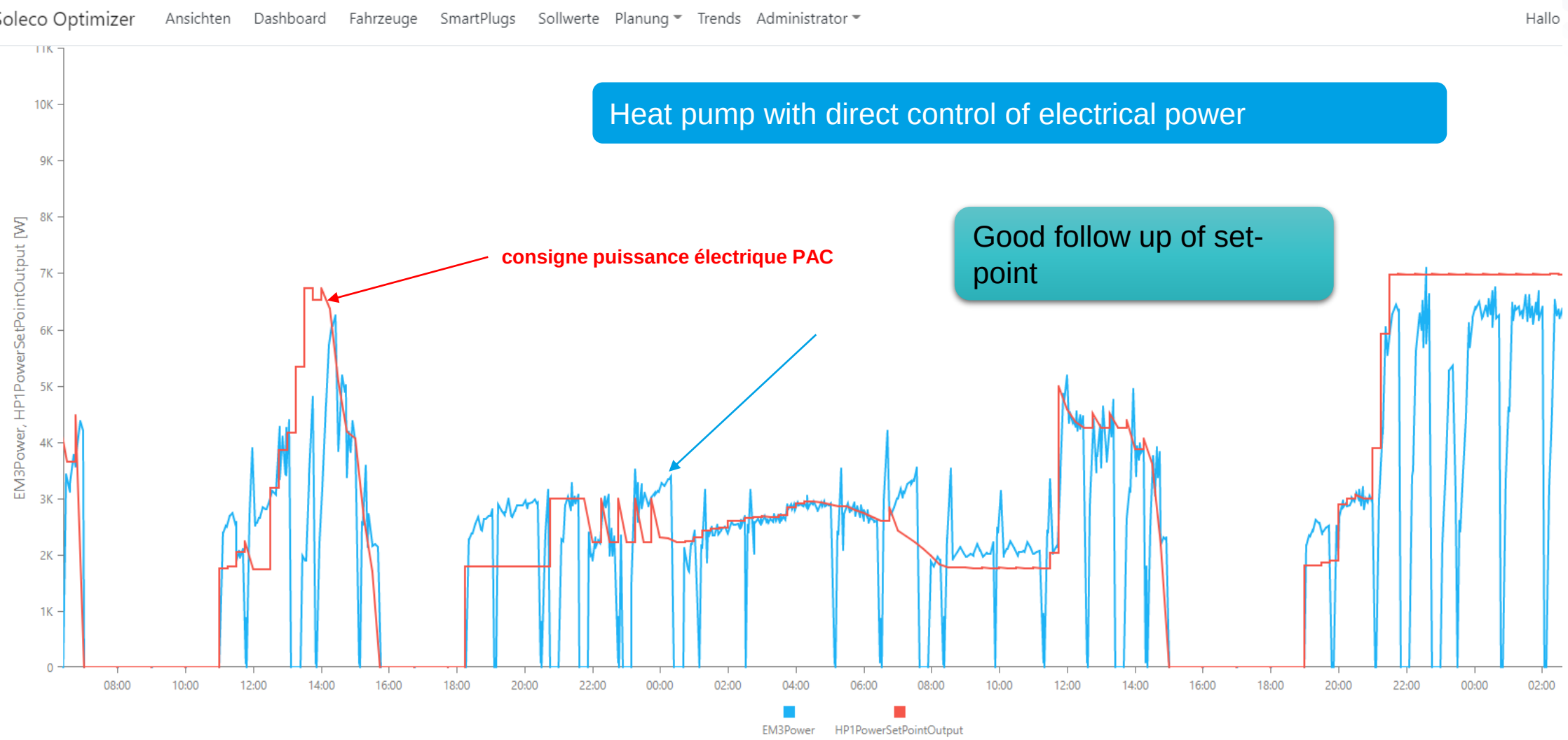
ENERGY MANAGEMENT IN INDIVIDUAL HOUSES AND MULTI-APARTMENT BUILDINGS

HOMSPHERE

ENERGY MANAGEMENT IN ENERGY COMMUNITY DISTRICT IN COLLABORATION

Example of (relatively) optimal interface for HP

Soleco AG
Solar for economy & ecology



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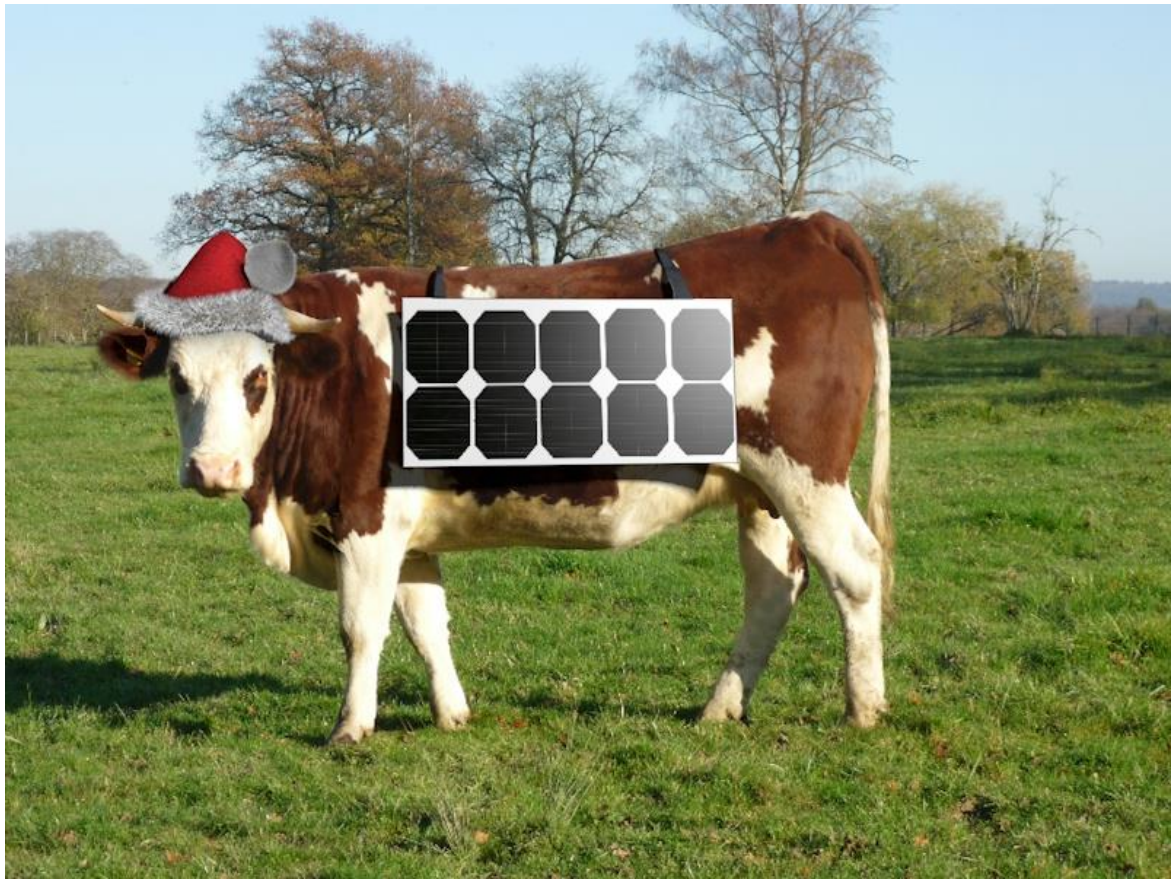
ENERGY COMMUNITY NEEDS TO MOVE FASTER…
HOPEFULLY MUCH MORE PV COMES SOON

SWITZERLAND, SENSITIVE TO ACCEPTANCE IN RURAL AND URBAN ENVIRONMENT

Sensitive to aesthetics



Neuchâtel, maison des associations, Swiss Solar Award 2015 «renovation category»

Over 20’000 “Megaslates” systems installed (3S solar solution), fast ramping up of Swiss production

New Production lines in Thun

Prix solaire
Suisse 2015

3S Swiss Solar Solutions | csem

WHAT DO ARCHITECTS WANT ?

Elegance and architecture
Transforming building and cities

CSEM as pioneer of transformative technologies for PV panes

Based on low cost c-Si modules, ….

White PV panels,
together with Solaxess

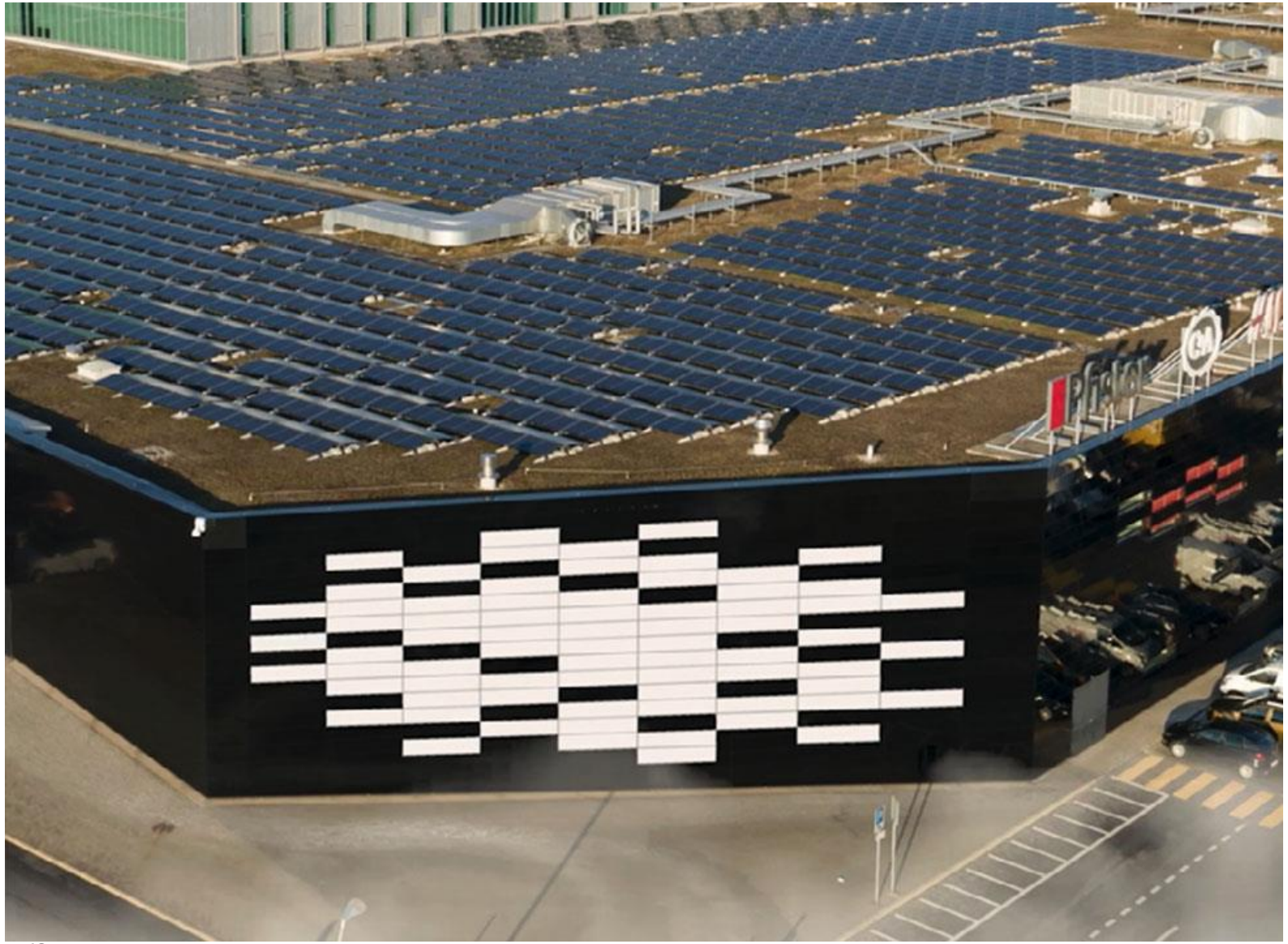
SOLAXESS
WHITE & COLOR SOLAR TECHNOLOGY

csem

SOLAXESS
WHITE & COLOR SOLAR TECHNOLOGY

csem

FAÇADE ACTIVE, MIGROS DE MARIN



SOLAXESS
WHITE & COLOR SOLAR TECHNOLOGY

EPFL | csem BE SMART

LA CHAUX-DE-FONDS

SOLAXESS
WHITE & COLOR SOLAR TECHNOLOGY
csem

Ecuvillens
One of the
Terra-cotta tones

With ISSOL, Solstis,
Userhuus, SFOE

Soutien des Service de
l’énergie et des biens
culturels de Fribourg

Prix solaire
Suisse 2018

hflu Höhere Fachschule Luzern

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Federal Office of Energy SFOE

ETAT DE FRIBOURG
STAAT FREIBURG

Schweizer Solrif®

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Prix solaire
Suisse 2019

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3S Solar Plus

csem

SOLAXESS
WHITE & COLOR SOLAR TECHNOLOGY

3S Solar Plus

csem

SOLAXESS
WHITE & COLOR SOLAR TECHNOLOGY

3S Solar Plus

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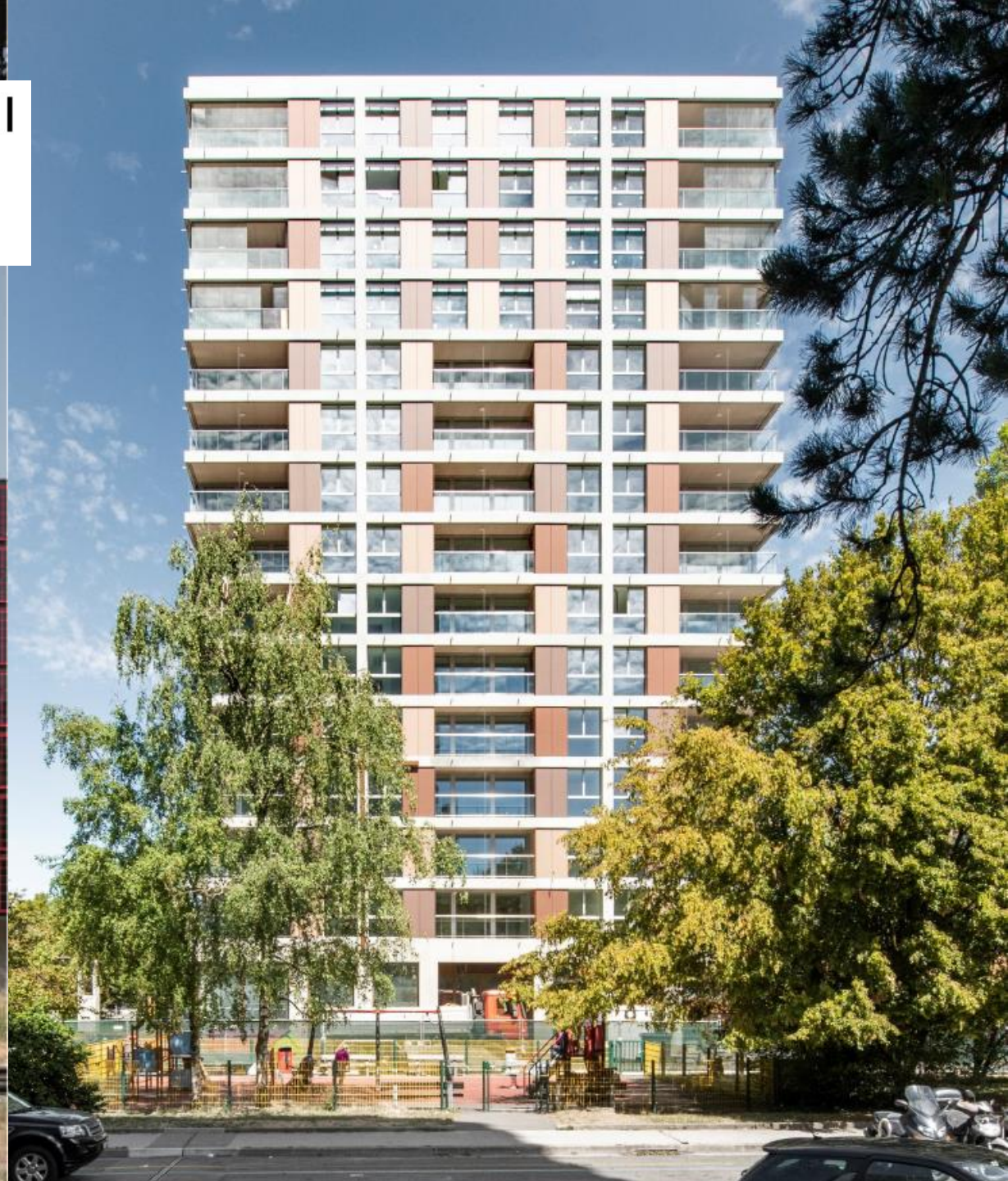
Solarwall

Architectural integrated photovoltaics

A Villars-Ste-Croix



FREE SUNS SOLAR ENERGY In Colombier/Morges | csem

FREE SUNS SOLAR ENERGY | csem

FREE SUNS SOLAR ENERGY | csem

Private house
Neuchâtel

Courtesy L.E.
Perret-Aebi

compáz

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INNOVATION IN SWITZERLAND

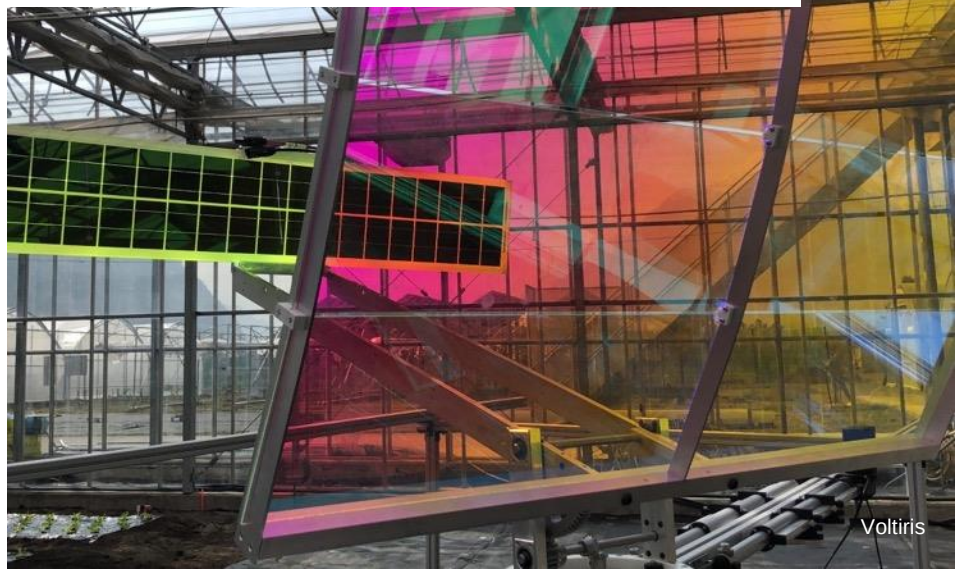
dhp

- Deployable PV systems

EPFL | csem

Agrivoltaics on the move

VOLTIRIS



insolight

hiperion
MAX SOLAR POWER

csem

THANKS FOR YOUR ATTENTION

Do you want to work with us sponsor our activiti
Dont’s hesitate to contact us !

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