

International Aspects of a Power-to-X Roadmap

Results of a study on behalf of the WEC Germany

18 October 2018

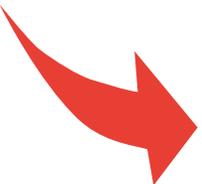
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Background: Power-to-X is arising as a key topic for the energy transition – nationally as well as internationally

Background and starting point

- The global energy system needs to fundamentally transform towards carbon-neutral energy sources over the next decades to meet the long term goals set in the Paris Agreement.
- The energy transition towards carbon-neutrality is based on a number of key elements such as
 - increasing the efficiencies of energy applications,
 - boosting the supply of renewable energy sources (RES), and
 - deploying other forms of carbon-neutral technologies, such as nuclear power or carbon capture and storage (CCS).



Focus of this study

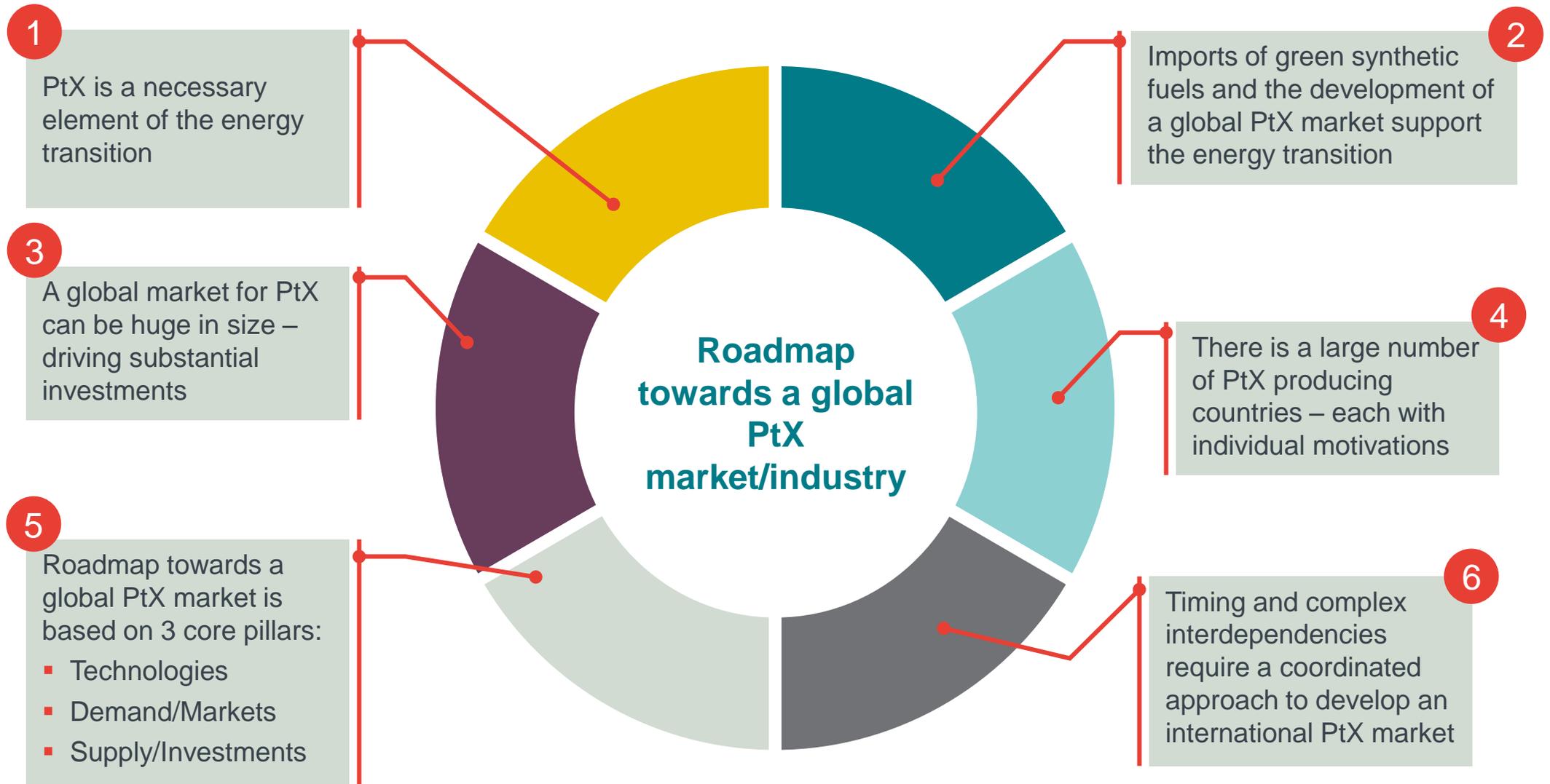
- We focus on synthetic fuels and hydrogen produced from renewable electricity (Power-to-X or PtX), analysing...
 - ...the potential future role of PtX in the global energy transition
 - ...potential PtX exporting countries (case studies)
 - ...the main pillars of a potential roadmap towards a future global PtX market



Approach

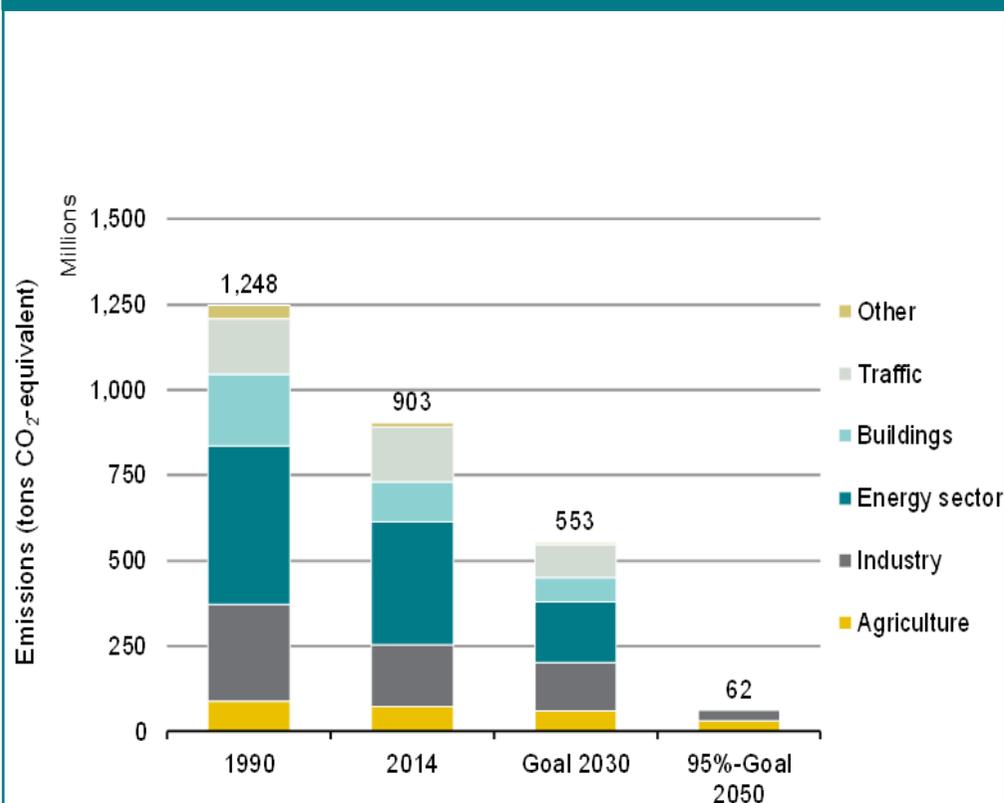
- Desk research
- Three workshops with WEC Germany members
- Interviews with PtX and country experts

The roadmap towards a global PtX industry is based on the requirements and opportunities of the global energy transition



PtX will be a key element for the transition of energy systems towards carbon-neutrality

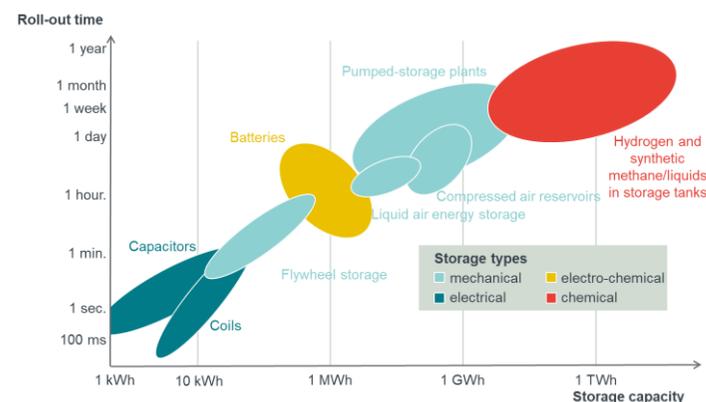
Ambitious climate targets require a de-fossilisation in all sectors



Source: Frontier Economics (historical values based on information from the Federal Environmental Agency: National greenhouse gas inventory 2017, final status 04/2017).

PtX provides essential benefits for the transition towards a carbon-neutral energy system

- Some sectors will inevitably require green synthetic fuels for decarbonisation
- An electricity system based solely on renewables will need massive storing of energy – this requires chemical fuels

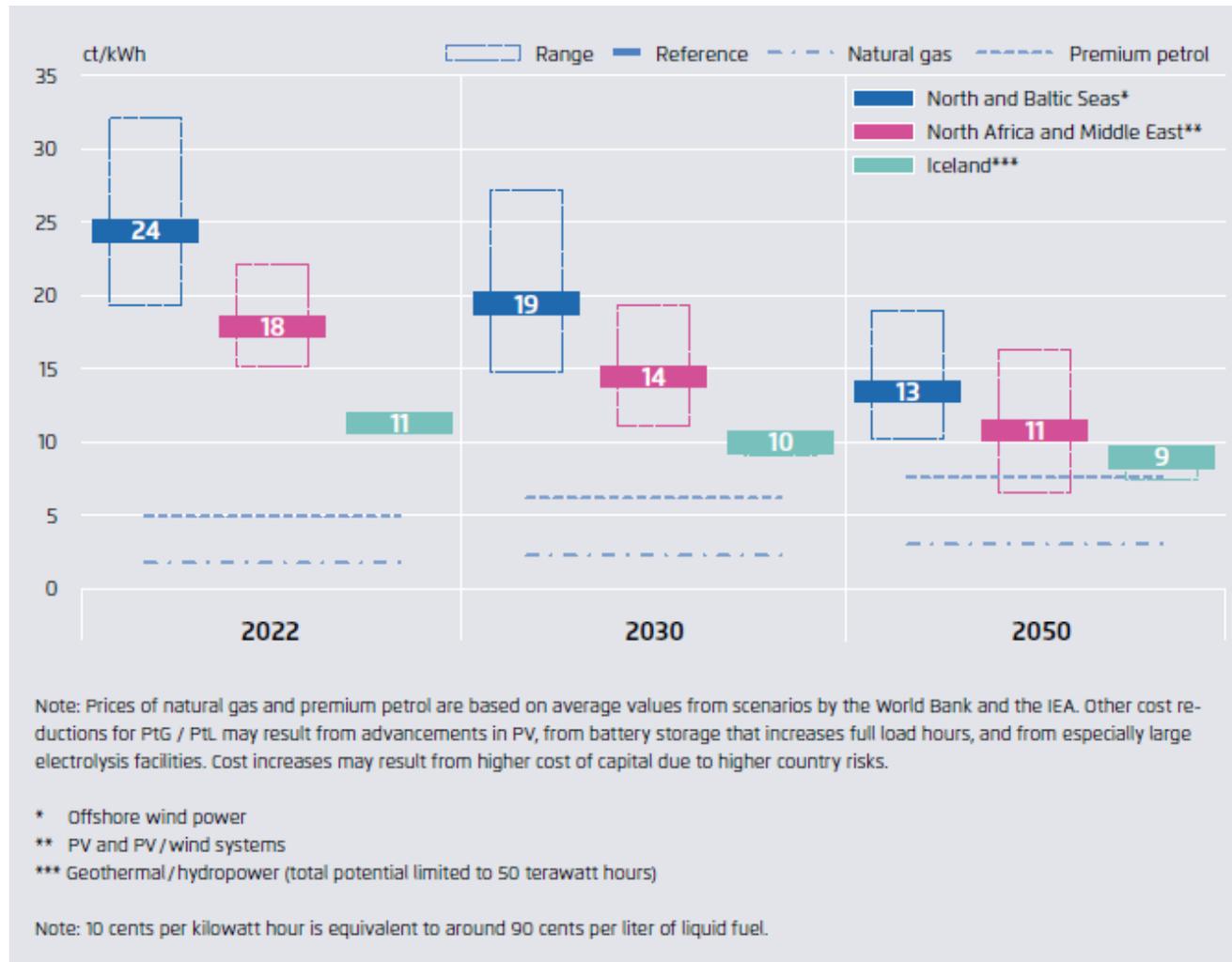


Source: Frontier Economics based on Sterner et al. (2014), and own analyses

- Use of existing infrastructure and applications – with positive implications on
 - System costs
 - Acceptance
 - Acceleration of the speed of the energy transformation

A global market for PtX makes sense – due to the availability of sites for RES-E and cost optimisation

Cost of synthetic fuels / methane



Source: Frontier Economics in: Agora Verkehrswende und Agora Energiewende (2018)

THESIS 1

Renewable energy will have to be imported (to DE/EU) in order to accommodate accelerating demand

THESIS 2

Boosting the scale of renewable energy imports will require chemical energy carriers, including PtX

THESIS 3

International PtX trade will help to accommodate the costs of the energy transition and can diversify the import portfolio

A future global PtX market will rise to a significant size

Corresponds to electrolyser capacity of 3,000-6,000 GW

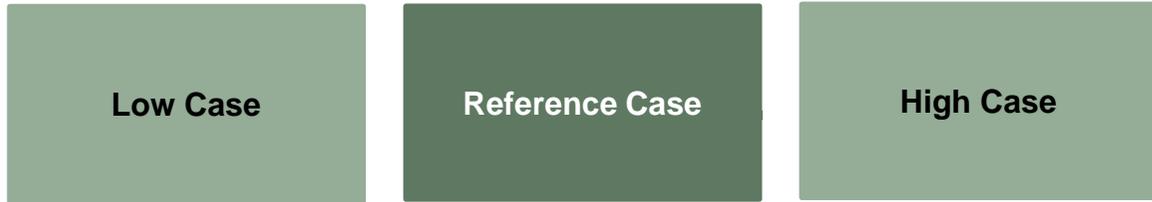
PtX market

| Low Case | Reference Case | High case |
|----------------|----------------|----------------|
| Ca. 10,000 TWh | Ca. 20,000 TWh | Ca. 41,000 TWh |

PtX final demand share



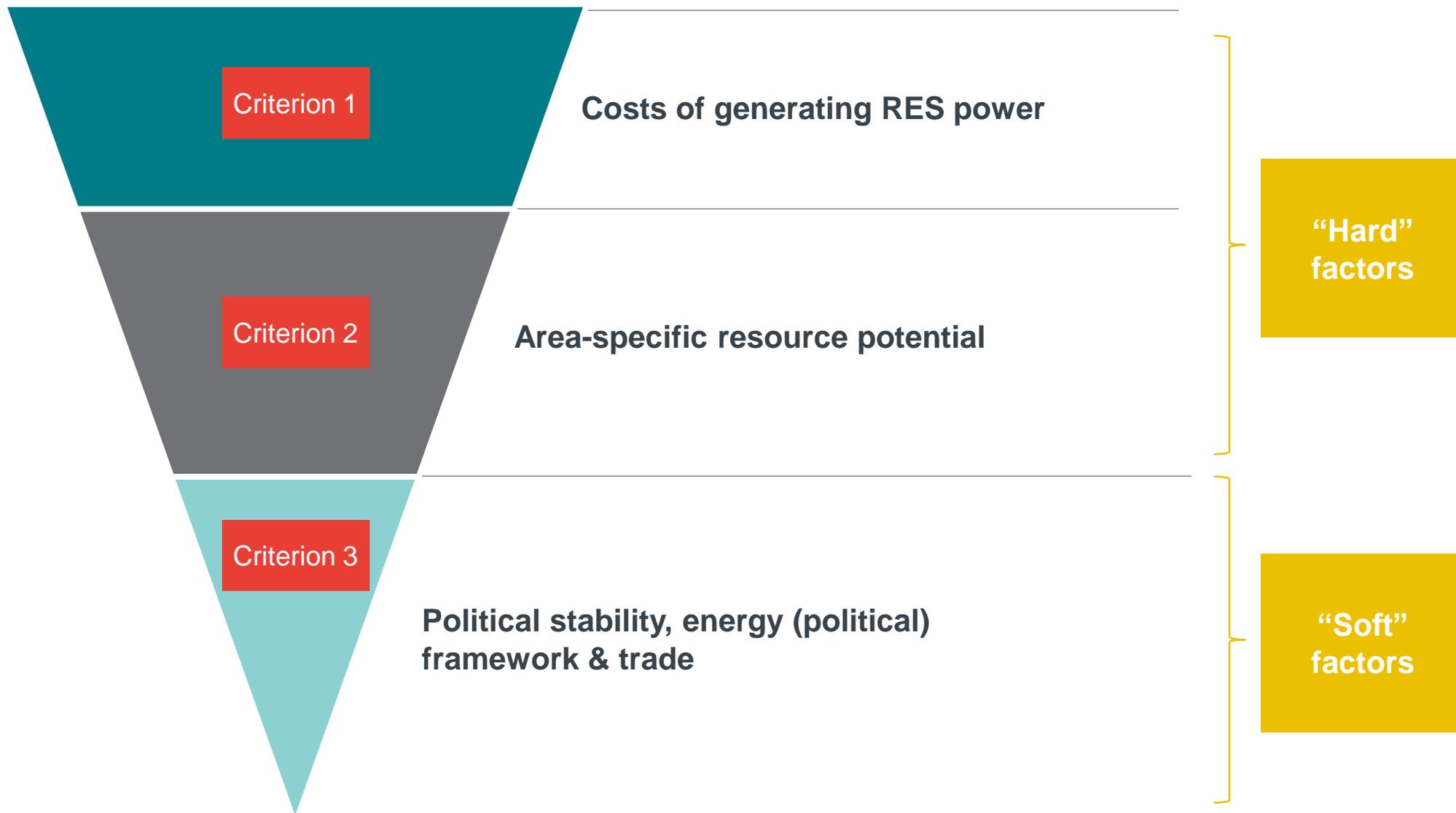
Scenarios based on assumed Market shares



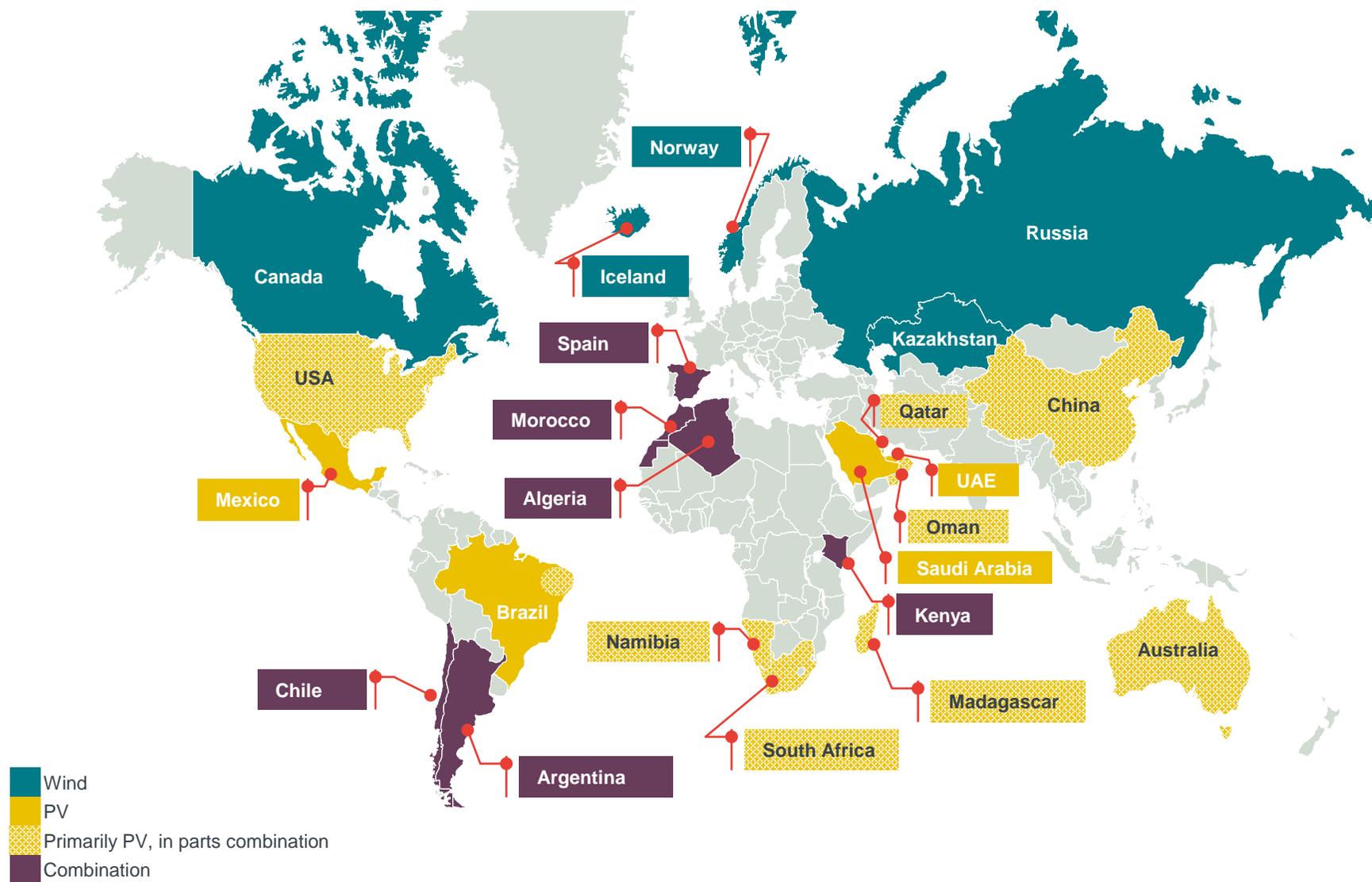
Division into sectors
Division into geographies



Potential PtX producing countries require a combination of various factors



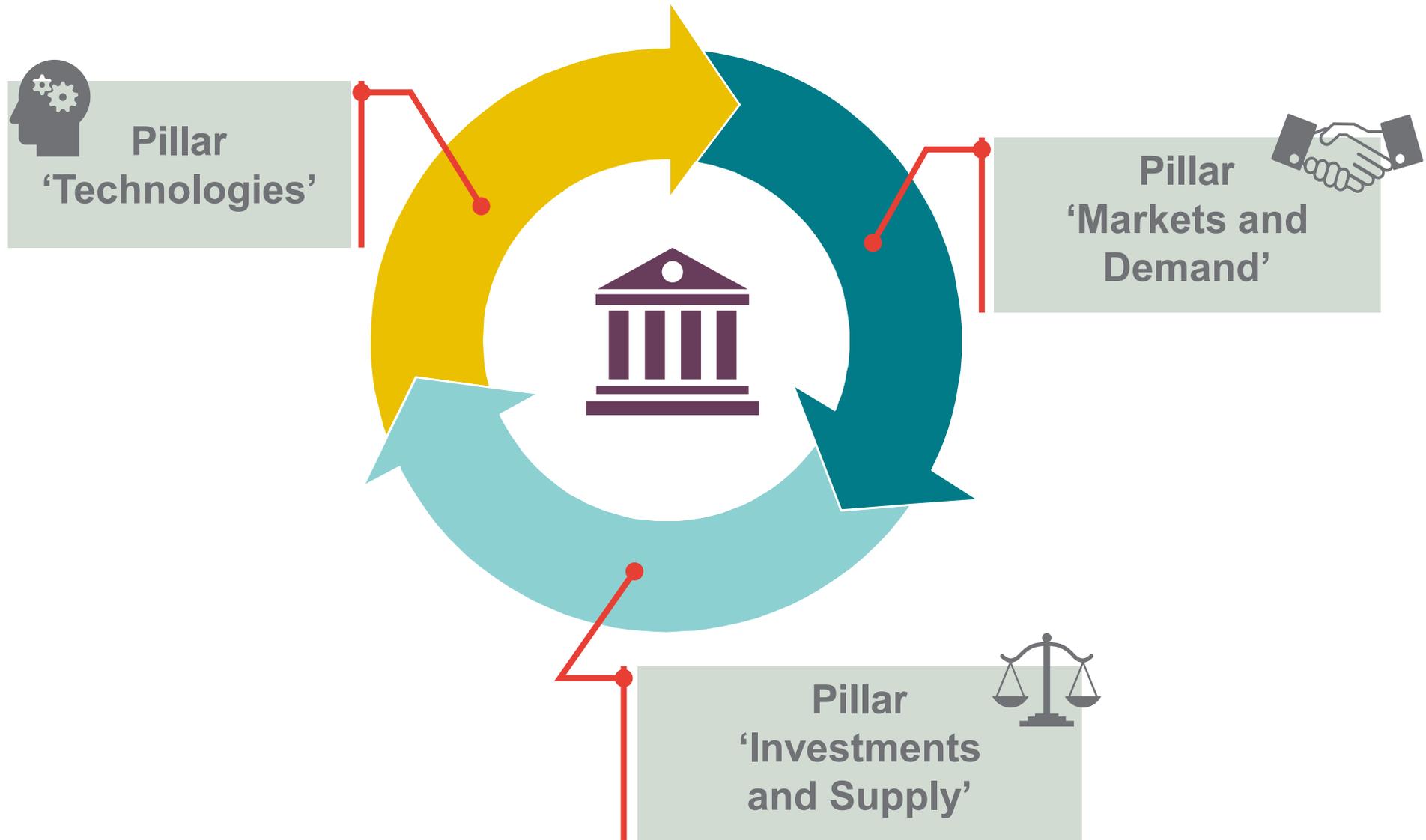
Various countries demonstrate strong potential for PtX production / exports ...



...however, potential PtX suppliers vary in terms of incentives and readiness to adjust

| Type | PtX motivation and readiness | Examples |
|--|---|---|
|  Frontrunners | <ul style="list-style-type: none"> ➤ Especially favourable in early stages of market penetration |  Norway |
|  Hidden Champions | <ul style="list-style-type: none"> ➤ PtX could readily become a serious topic if facilitated appropriately |  Chile |
|  Giants | <ul style="list-style-type: none"> ➤ Provide order of PtX magnitudes demanded in mature market |  Australia |
|  Hyped Potentials | <ul style="list-style-type: none"> ➤ Potential to lead technology development; may depend strongly on solid political facilitation |  Morocco |
|  Converters | <ul style="list-style-type: none"> ➤ Strong motivation for PtX export technology development; may require political facilitation |  Saudi Arabia |
|  Uncertain Candidates | <ul style="list-style-type: none"> ➤ May drive PtX technology development, export uncertain |  China |

A PtX roadmap describing the path towards an international market requires a sustainable framework





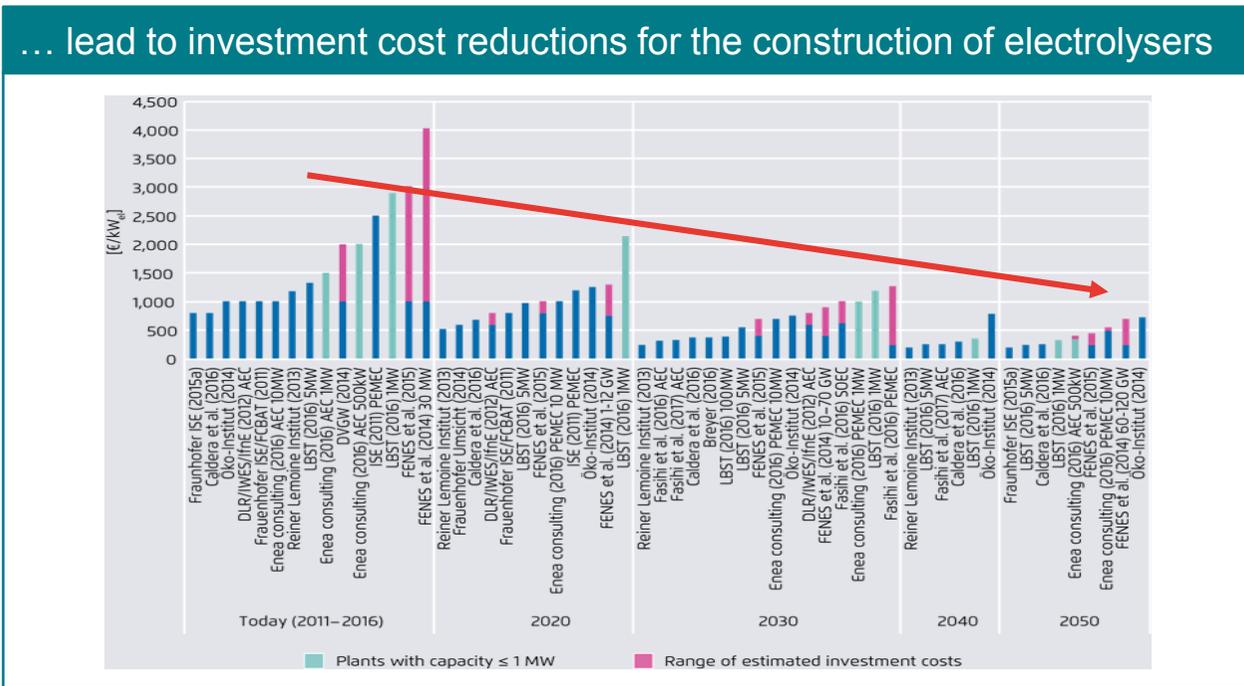
Pillar ‘Technologies’: Development of a PtX industry requires further technological progress



Source: Siemens

Key drivers to achieve cost savings...

- Scaling up of plant sizes
- Standardisation of components / modules and of processes to build installations



Source: Agora Verkehrswende, Agora Energiewende and Frontier Economics (2018)



Illustrative

Technologies

2023 Regulatory driven market entry of PtX as a direct substitute for fossil products

2030 Single market for green (PtX) / blue (CCS) hydrogen

2035 CO₂- and H₂-transport infrastructure has become integral part of the energy system

PtX complemented with other carbon neutral options ("blue" fuels/ bio)

Increasing usage of Direct Air Capture and built up of a dedicated CO₂ infrastructure

CO₂ captured from industry and biomass

Establishment of new dedicated infrastructure for hydrogen and other PtX (ammonia)

Usage of existing infrastructure with conversion to hydrogen synthetic fuels

Usage of existing infrastructure for blending PtX with fossil fuels

2020 <200 MW electrolyzers installed p.a. in the EU

2028 >10 GW PtX capacity added globally p.a

2040 >100 GW PtX capacity added globally p.a

PtX costs to benefit from systematic development of low-cost production locations

PtX costs to decrease through upscaling of technology

2024 Several large scale pilot plants in remote area for export to EU

2032 "Giga Factory" for standardised PtX production units

2042 Systematic built up of PtX production units in (increasingly remote) areas with low energy-costs

Commoditisation and large scale production of key technologies (e.g. electrolyzers)

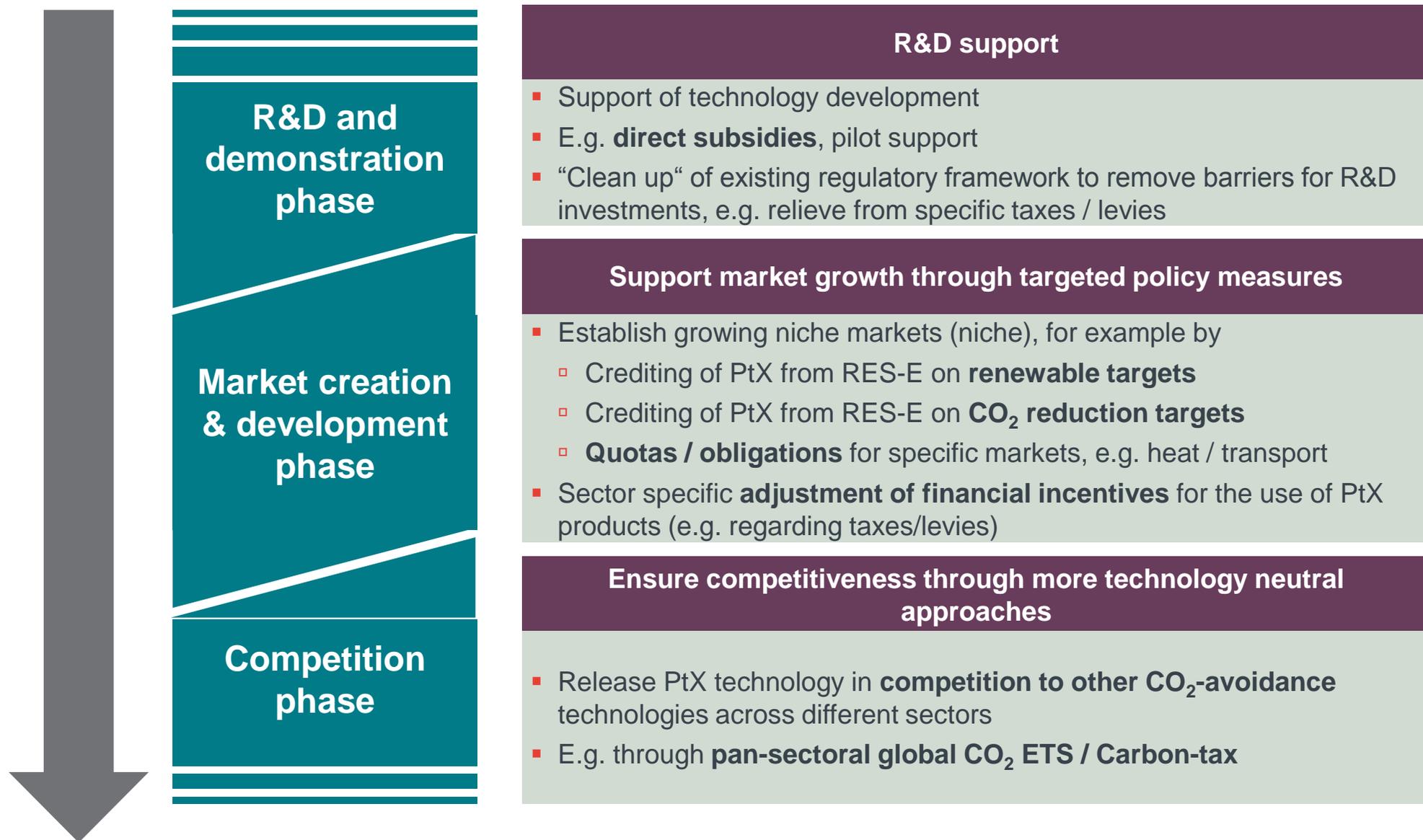
Standardisation and modularisation of components generates economies of scale

Individual manufacturing of system components

2020 2030 2040 2050

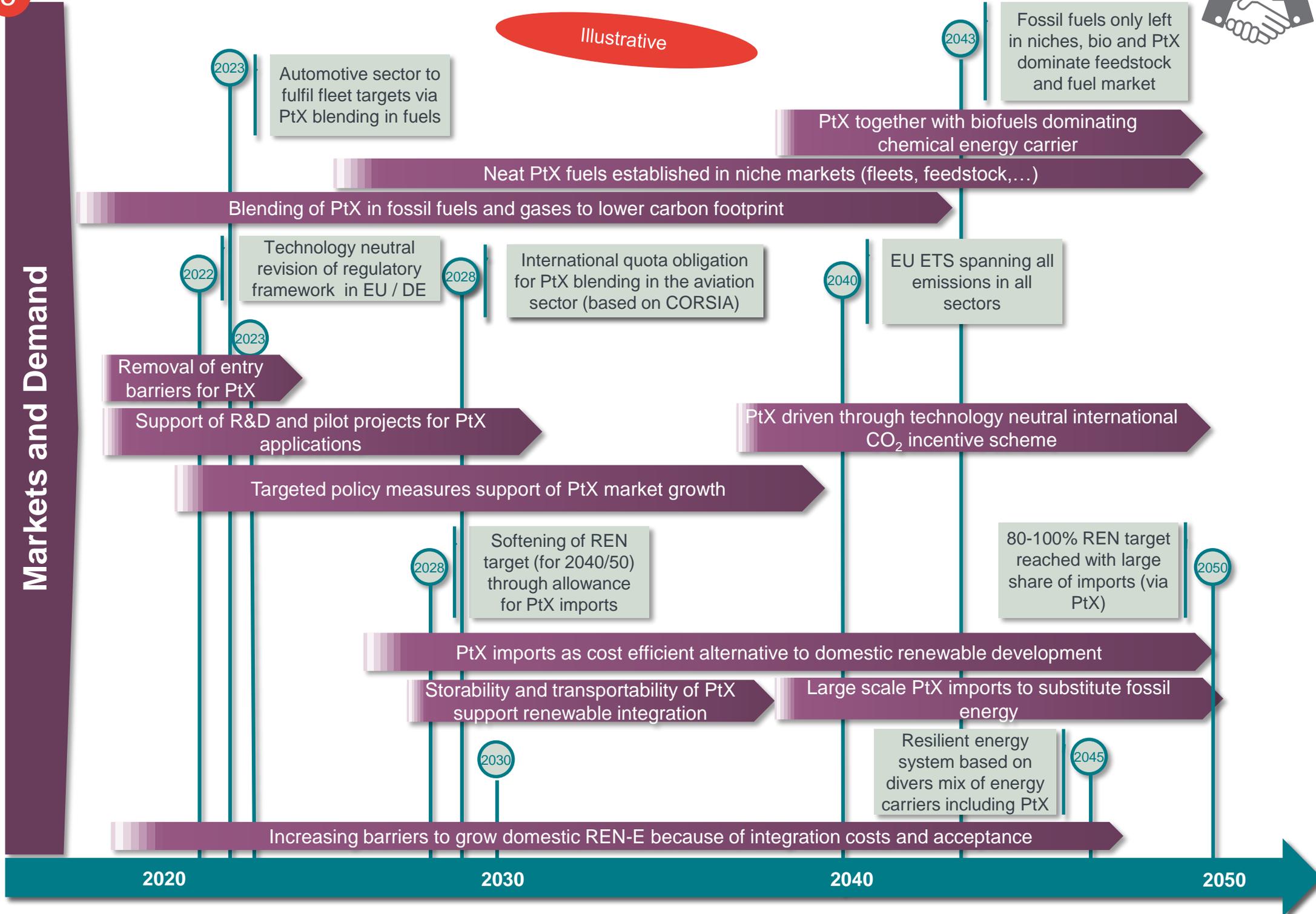


Pillar ‘Markets and Demand’: Regulation and political facilitation is needed to create PtX markets and demand



Markets and Demand

Illustrative



2020

2030

2040

2050



Pillar 'Investments and Supply': Politicians can help to reduce risks for investors



Place PtX on the **international climate policy and renewable agenda**



Financial instruments to mitigate the impact of country risks for investors



Promoting **bilateral co-operations and collaboration** such as energy partnerships



Backing of investments by multilateral **energy treaties and agreements**



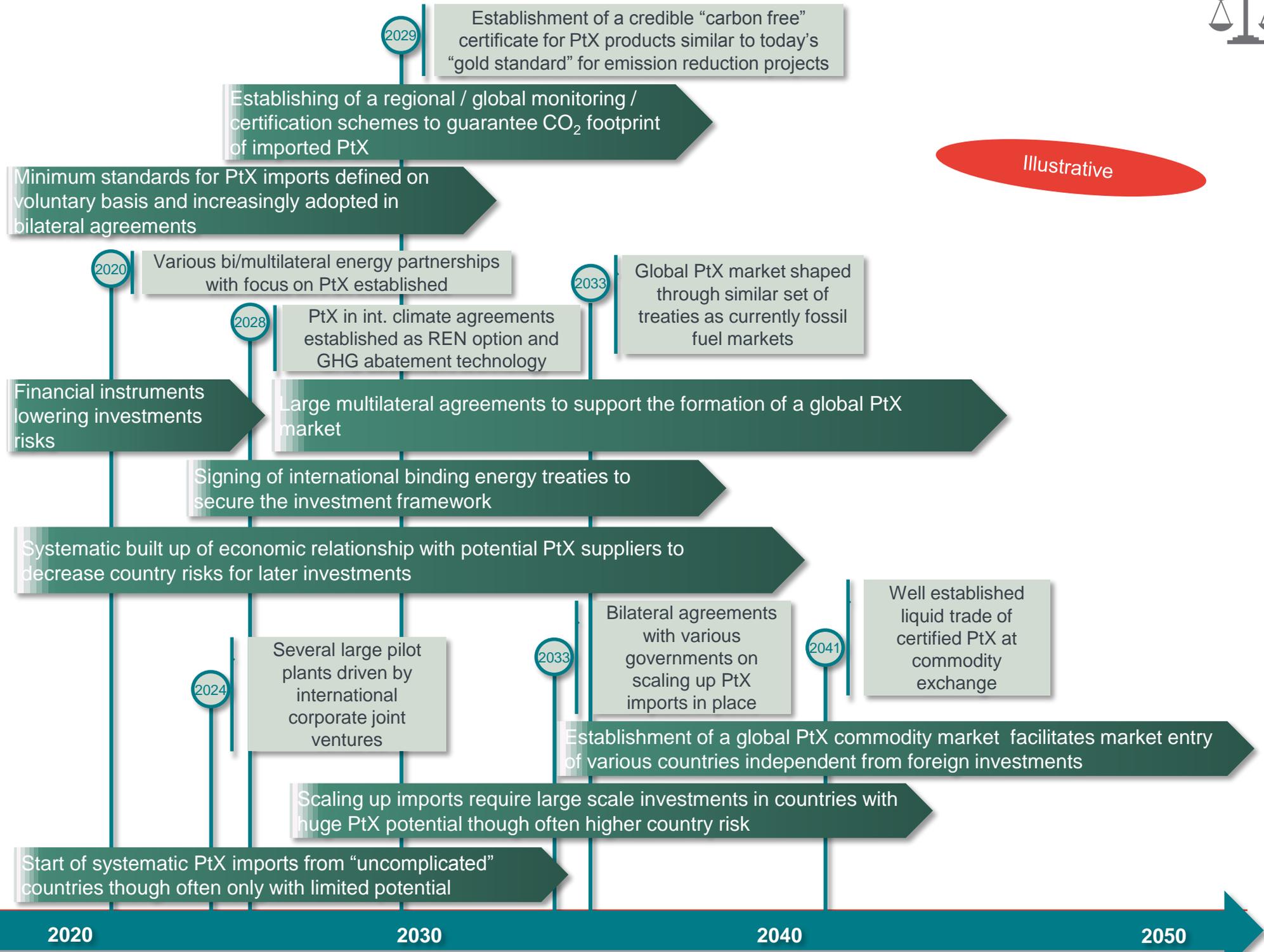
Establishing **criteria for sustainability assessment**



Establishing a **green certification system**

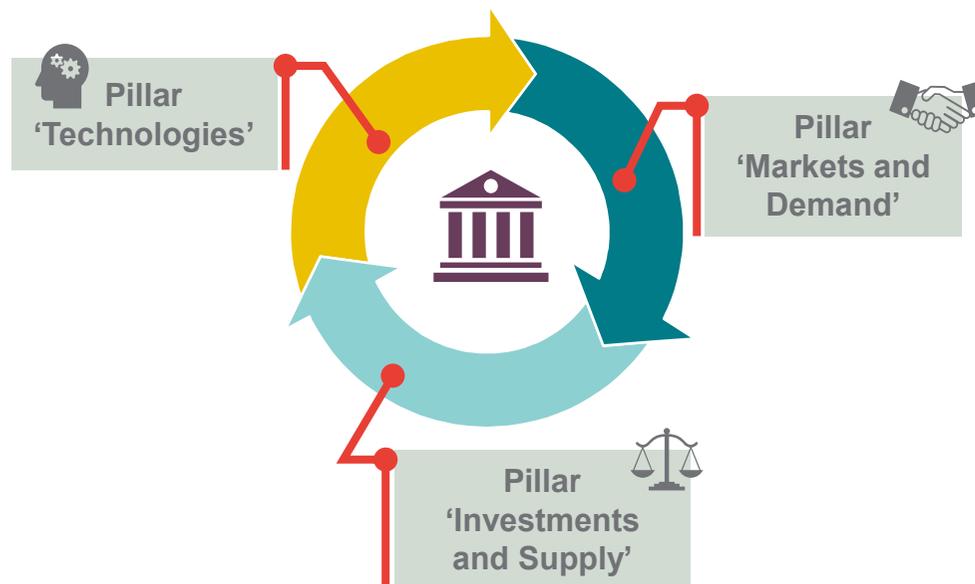


Supply and Investments



Illustrative

Timing and complex interdependencies require a coordinated approach to develop a global PtX market – political action is needed as of today





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