Fraunhofer ISE


# HYreland Intermediate Results

## Fraunhofer ISE Approach for Selection of the Best Sites for large-scale Renewables and Power-to-X Hubs in Ireland

Lucas Edenhofer, Marius Holst, Robert Szolak and Christoph Hank
Fraunhofer ISE, Hydrogen Technologies
Freiburg May, 2025

# The Fraunhofer Institute for Solar Energy Systems ISE

## Performing research for the energy transition for over forty years

**Photovoltaics**

**Heat and Buildings**

**Power Solutions**

**Hydrogen Technologies**
- Fuel Cell
- Sustainable Synthesis Products
- Electrolysis and Hydrogen Infrastructure





Fraunhofer ISE

# Business Area Hydrogen Technologies at Fraunhofer ISE

## Defossilisation of transport, chemicals and process heat


### Fuel Cell

PEM fuel cell characterization, modelling, and manufacturing,
Integration in mobility and drivetrains

### Electrolysis and $H_2$ Infrastructure

Hydrogen production by water electrolysis, hydrogen injection, Power-to-X simulations and techno-economic assessments, technical consulting

### Sustainable Synthesis Products

Development of catalysts and processes, techno-economic and life cycle assessments, technical consulting

**>150**
**Employees**

**15 MEUR/a**
**Budget**

**>30 Years**
**Experience in the field of hydrogen and thermochemical processes**



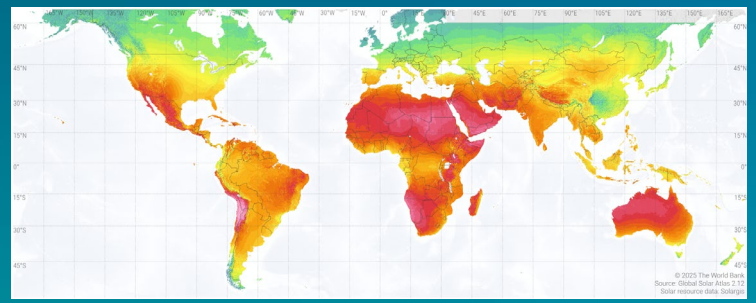


Fraunhofer ISE

# Where are the best locations for $H_2$ & PtX hubs?

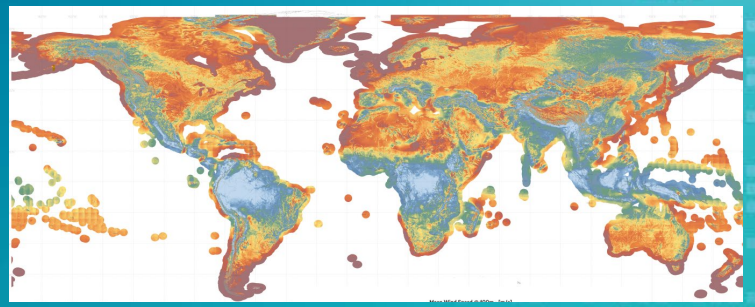
# Are sunshine and wind enough?

Solar irradiation



+

Wind speed



=






[1]: Global Solar Atlas 2.0, a free, web-based application is developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalsolaratlas.info
[2]: Global Wind Atlas version 3.3, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas version 3.3 is released in partnership with the World Bank Group, utilizing data provided by Vortex, using funding provided by the ESMAP. For additional information: https://globalwindatlas.info

Fraunhofer ISE

Fraunhofer ISE

# Our Approach

## GIS-based Site Suitability Assessments for Renewable Energy, Hydrogen and Power-to-X

# GIS-based Site Suitability Assessment

## **Step I**: Identification of optimal Renewables locations

Step I | Step II

### 1.0 System boundary

- RE technology and capacity
  - Offshore wind: … $MW_{el}$
  - Onshore wind: … $MW_{el}$
  - Solar PV: … $MW_{el}$
  - CSP: … $MW_{el}$
  - …
- RE technology selection
- Spatial boundary
- Temporal boundary

### 1.1 Restriction areas

- 25 - 33 restriction types per RE technology, including co-location and co-usage
- Restriction area density
- Appropriate setback distances
- Compliance with law
- Protection of cultural & natural heritage

### 1.2 Suitability criteria

- > 7 suitability criteria per RE technology
- Reflecting solar and wind resources
- Further factors concerning project feasibility and technical / economic aspects

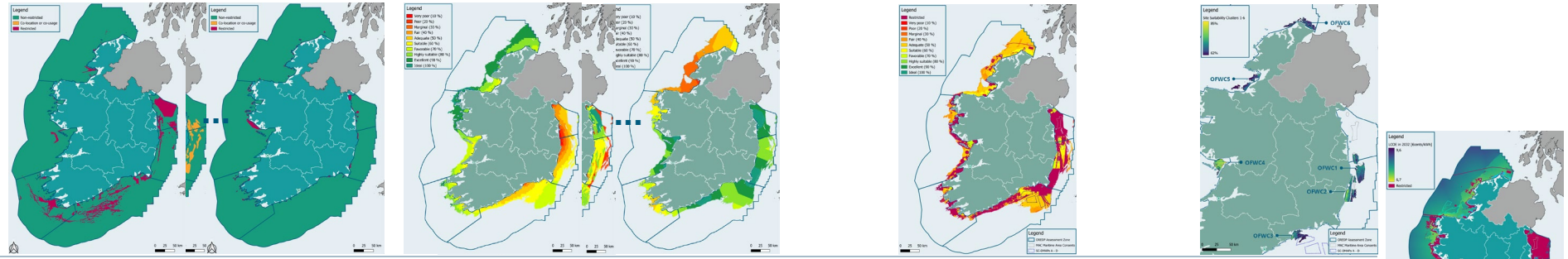
### 1.3 Site suitability

- Suitability criteria weighting via the analytic hierarchy process to establish criteria relevance based on expert input and scientific literature
- Combination of restriction areas with weighted suitability criteria to generate the site suitability score

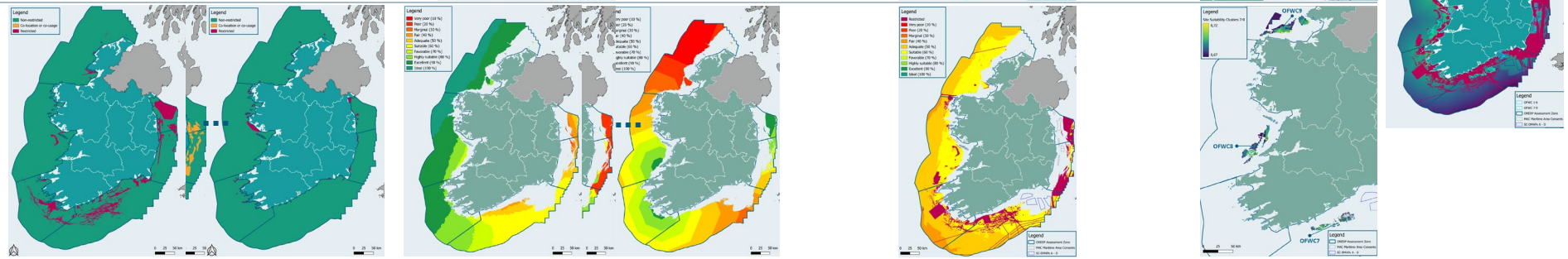
### 1.4 Site clusters & LCOE

- Clustering of areas with high site suitability scores to host the necessary renewable capacity
- In-depth cluster assessment with relevant KPIs
- Estimation of theoretical RE production potential and LCOE

**Offshore wind - Fixed**



**Offshore wind - Floating**





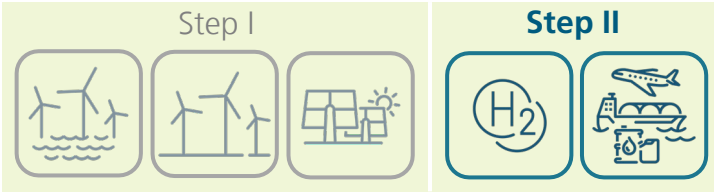


**Identification and evaluation of optimal renewable energy production sites for the specified PtX supply chains with regard to economic competitiveness and project feasibility**

Fraunhofer ISE

# GIS-based Site Suitability Assessment

## **Step II**: Identification of optimal $H_2$ and PtX hub locations




### 2.0 System boundary

- Power-to-X pathways
  - Hydrogen
  - Ammonia
  - Methanol, DME & eSAF
- PtX production volume
- Offtake
  - Domestic offtake
  - International export
- Temporal boundary

### 2.1 Suitability criteria

- 14 - 16 suitability criteria per specified PtX supply chain
- Based on the identified renewable energy clusters
- Reflecting economic competitiveness, sustainability and technical feasibility

### 2.2 Site suitability

- Suitability criteria weighting via the analytic hierarchy process to establish criteria relevance based on expert knowledge
- Overlay of the individual suitability criteria with regard to their weighting to generate the site suitability score

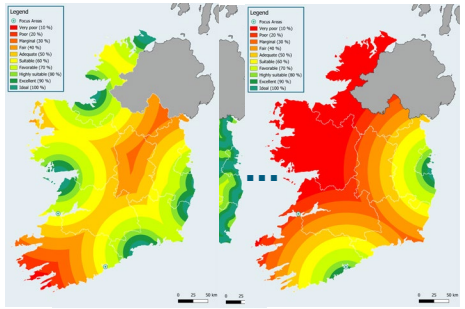
### 2.3 Site evaluation

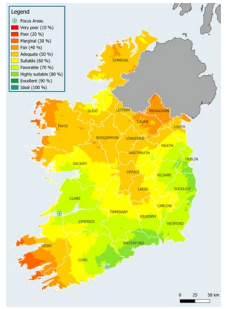
- Identification of promising PtX hub locations and corresponding RE clusters
- In-depth analysis of promising PtX hubs with regard to renewable energy clusters, supply chain options, additional infrastructure demand & synergy potential

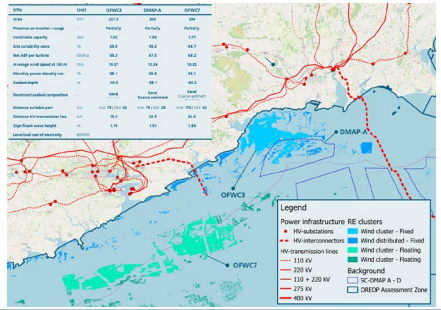
### 2.4 TEA-Parameters

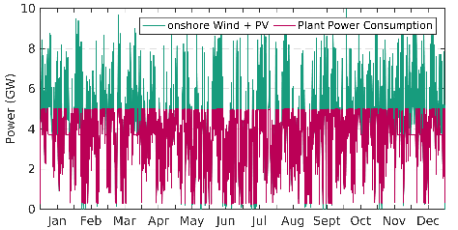
- Location-specific parameters of the various supply chain steps for subsequent techno-economic assessment
- Energy production time series for the selected clusters based on typical meteorological years (TMY) in hourly resolution

**Power-to-Hydrogen**

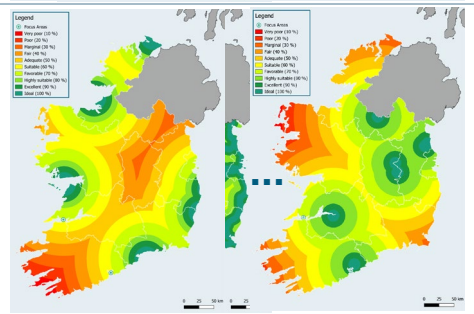


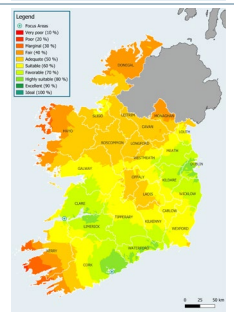


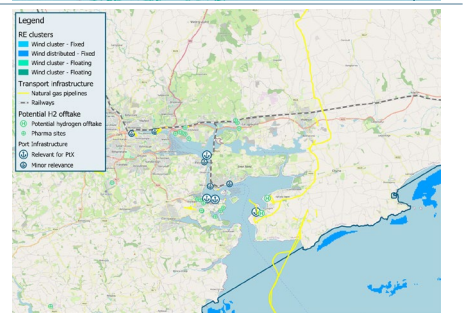


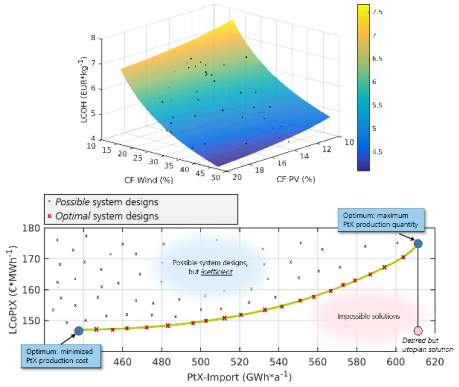




**Power-to-SAF**












**Identification and evaluation of optimal hydrogen and PtX hub locations with regard to economic competitiveness and project feasibility**

Fraunhofer ISE

Fraunhofer ISE

# Results from HYreland

HYreland

GIS-based site suitability assessments for RE, $H_2$ and PtX

# Results from HYreland

## The Landmark Study for a large-scale Green $H_2$ and eFuels Production in Ireland

## Research Goal

**Assessment of green hydrogen and PtX production and export from Ireland to Germany, focusing on techno-economic and ecological aspects within a cross-border value chain.**

## Hard Facts

- **Project duration**: 01.11.2024 – 31.10.2025 (12 months)
- **Funding German Side**: Federal Ministry of Education and Research - BMBF
- **Management organization**: Project Management Jülich - PtJ

*Paul Lennon (ESB), David Gill (German Ambassador to Ireland), Keelan Glennane (ESB) and Charlie Brophy (DECC); Source: RTE*


## Project partners

- **Electricity Supply Board ESB (Keelan Glennane)**
- **Fraunhofer Institute for Solar Energy Systems ISE (Christoph Hank)**
- **International Energy Research Centre IERC (Pádraig Lyons)**
- Associated Partners: Duisport, IHK Elbe-Weser, Wirtschaftsförderung Landkreis Stade, Wirtschaftsförderung Hansestadt Stade, Department of the Environment, Climate and Communications DECC

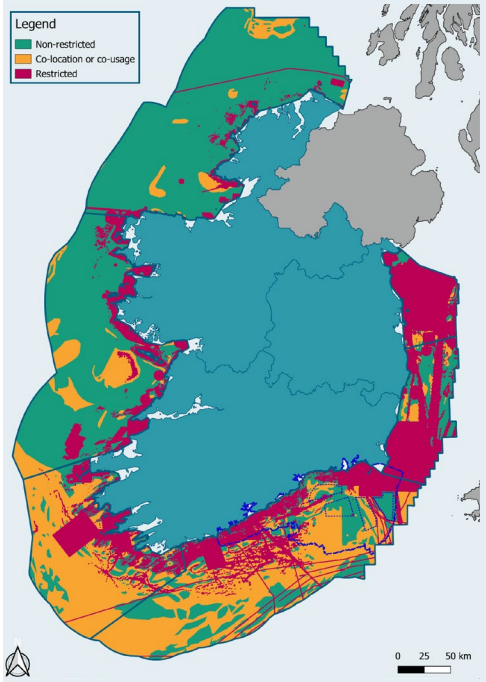


H2 HYreland
Federal Ministry of Education and Research
Funded by the Federal Ministry of Education and Research (FKZ 03SF0788)
Fraunhofer ISE

# Results from HYreland

## Restriction areas – RE

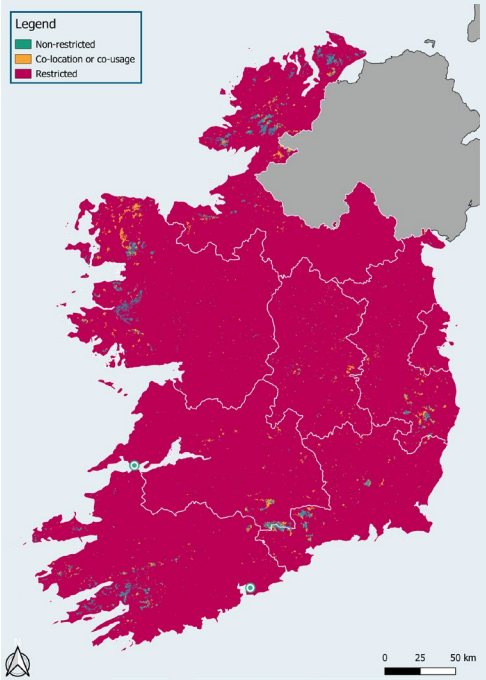
### Offshore wind




| | OREDP |
|---|---|
| R-OF-OWT | 0.2% |
| R-OF-TWE | 0.6% |
| R-OF-PIP | 0.5% |
| R-OF-AWS | 0.1% |
| R-OF-SWS | 0.0% |
| R-OF-CCS | 0.2% |
| R-OF-PAF | 0.0% |
| R-OF-VER | 5.9% |
| R-OF-NAV | 0.0% |
| R-OF-DRS | 0.1% |
| R-OF-CAB | 2.2% |
| R-OF-FIR | 7.3% |
| R-OF-FIG | 34.1% |
| R-OF-AQS | 0.3% |
| R-OF-WDS | 1.1% |
| R-OF-MIS | 1.9% |
| R-OF-AES | 0.1% |
| R-OF-ARS | 2.2% |
| R-OF-SBS | 3.4% |
| R-OF-SBD | 0.0% |
| R-OF-SBG | 5.0% |
| R-OF-IBA | 1.6% |
| R-OF-SAC | 4.6% |
| R-OF-SPA | 7.4% |
| R-OF-RWL | 0.0% |
| **Restricted** | **27%** |
| **Co-location /-usage** | **26%** |
| **Non-restricted** | **47%** |

- Largest restrictions by special protection areas, busy fishing and vessel routes
- Restriction area concentration near coastline, especially in the east
- DMAP A-D almost completely non-restricted

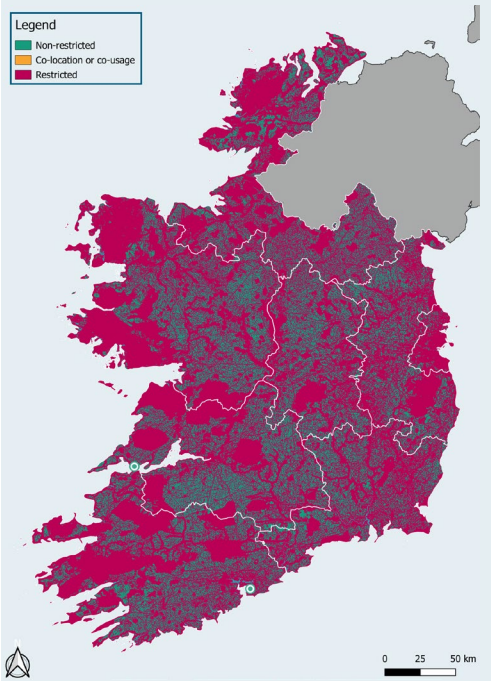
### Onshore wind




| | IRL |
|---|---|
| R-ON-ONT | 3.3% |
| R-ON-GPV | 0.4% |
| R-ON-TRL | 9.0% |
| R-ON-ROA | 8.9% |
| R-ON-RAI | 1.4% |
| R-ON-AIR | 1.2% |
| R-ON-NAV | 0.8% |
| R-ON-MIN | 0.1% |
| R-ON-MIS | 0.1% |
| R-ON-BUI | 87.5% |
| R-ON-WAS | 3.2% |
| R-ON-COS | 0.1% |
| R-ON-MUD | 0.1% |
| R-ON-SWA | 0.0% |
| R-ON-CUL | 6.1% |
| R-ON-FOR | 13.4% |
| R-ON-PEA | 6.6% |
| R-ON-RIV | 7.4% |
| R-ON-LAK | 3.6% |
| R-ON-MAR | 0.5% |
| R-ON-GRS | 1.3% |
| R-ON-IBA | 8.2% |
| R-ON-SAC | 16.0% |
| R-ON-SPA | 8.7% |
| R-ON-NHA | 1.4% |
| R-ON-UNE | 1.2% |
| R-ON-RWL | 0.8% |
| R-ON-WAW | 3.1% |
| R-ON-ASM | 0.0% |
| R-ON-BFB | 0.17% |
| R-ON-RFL | 2.29% |
| R-ON-CFL | 0.59% |
| **Restricted** | **97.4%** |
| **Co-location /-usage** | **1.1%** |
| **Non-restricted** | **1.5%** |

- Largest restrictions by buildings and special areas of conservation with co-location /-usage on cultivated areas and forests
- Isolated non-restricted areas tends to be closer to the coast

### Photovoltaics




| | IRL |
|---|---|
| R-PV-ONT | 1.4% |
| R-PV-GPV | 0.4% |
| R-PV-TRL | 9.0% |
| R-PV-ROA | 8.9% |
| R-PV-RAI | 1.4% |
| R-PV-AIR | 0.1% |
| R-PV-NAV | 0.0% |
| R-PV-SSZ | 1.8% |
| R-PV-MIN | 0.1% |
| R-PV-MIS | 0.1% |
| R-PV-BUI | 55.5% |
| R-PV-WAS | 3.2% |
| R-PV-COS | 0.1% |
| R-PV-MUD | 0.1% |
| R-PV-SWA | 0.0% |
| R-PV-CUL | 6.1% |
| R-PV-FOR | 13.4% |
| R-PV-PEA | 6.6% |
| R-PV-RIV | 0.6% |
| R-PV-LAK | 1.9% |
| R-PV-MAR | 0.3% |
| R-PV-GRS | 1.3% |
| R-PV-IBA | 8.2% |
| R-PV-SAC | 16.0% |
| R-PV-SPA | 8.7% |
| R-PV-NHA | 1.4% |
| R-PV-UNE | 1.2% |
| R-PV-RWL | 0.8% |
| R-PV-WAW | 3.1% |
| R-PV-BFB | 0.2% |
| R-PV-RFL | 2.29% |
| R-PV-CFL | 0.59% |
| **Restricted** | **70%** |
| **Co-location /-usage** | **0%** |
| **Non-restricted** | **30%** |

- Largest restrictions by buildings, special areas of conservation and forests
- Non-restricted areas evenly distributed throughout the mainland with higher restriction concentration in the western coastal region





- Clear focus on offshore wind for Power-to-X
- Combination with ground-mounted solar photovoltaics

H2 HYreland
Federal Ministry of Education and Research
Funded by the Federal Ministry of Education and Research (FKZ 03SF0788)

Fraunhofer ISE

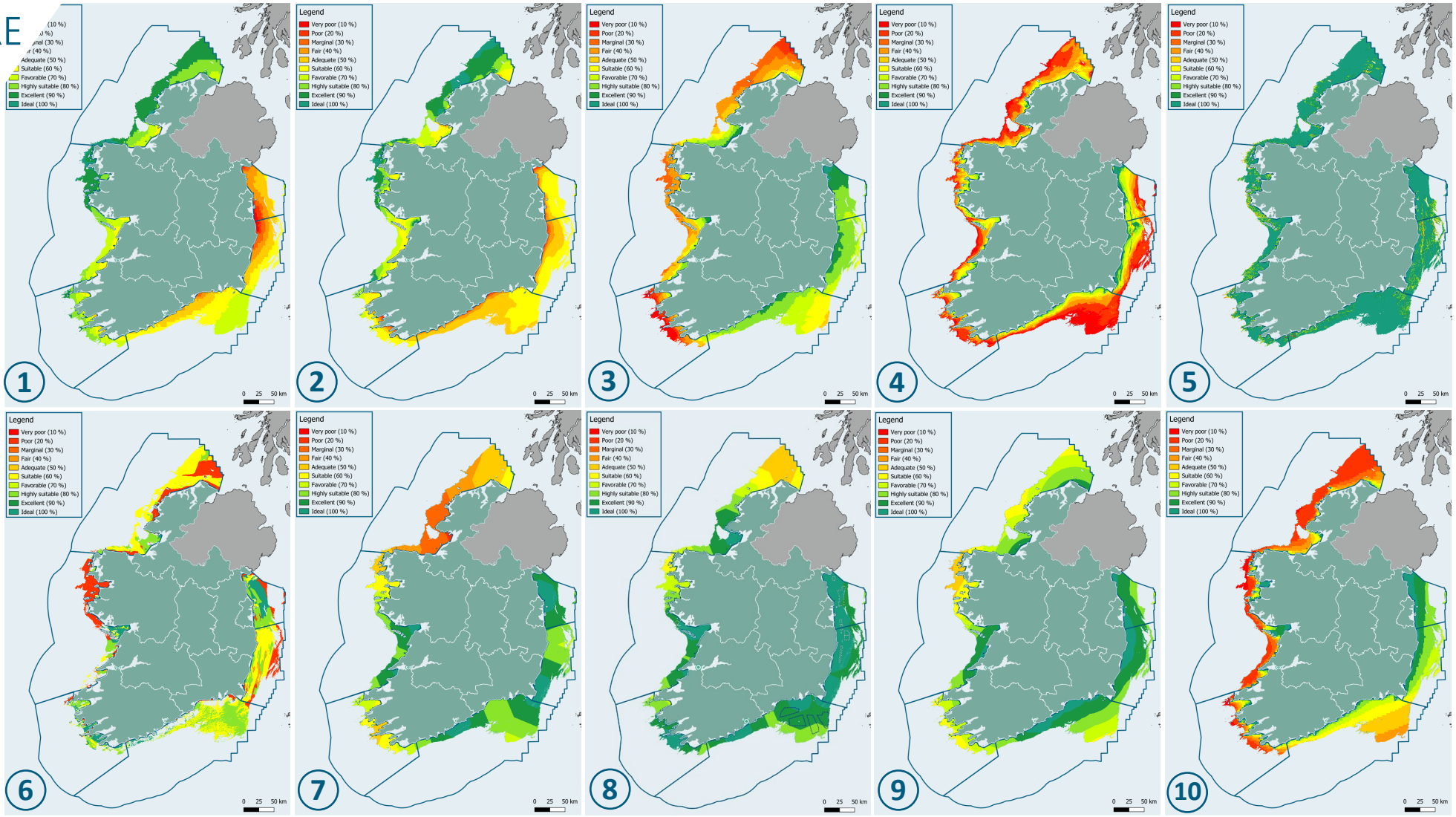
# Results from HYreland

## Suitability criteria – RE

### Offshore wind - Fixed

- Most important criteria regarding economic performance & project feasibility
- Differentiation between foundation types – fixed & floating
- Weighting by ESB experts
- Considered criteria:

1 Annual electricity production
2 Power density at 150 m
3 Power density variability
4 Seabed depth
5 Seabed slope
6 Seabed composition
7 Suitable ports – Installation
8 Suitable ports – O&M
9 Transmission lines ≥ 220 kV
10 Significant wave height








HYreland
Federal Ministry of Education and Research
Funded by the Federal Ministry of Education and Research (FKZ 03SF0788)
Fraunhofer ISE

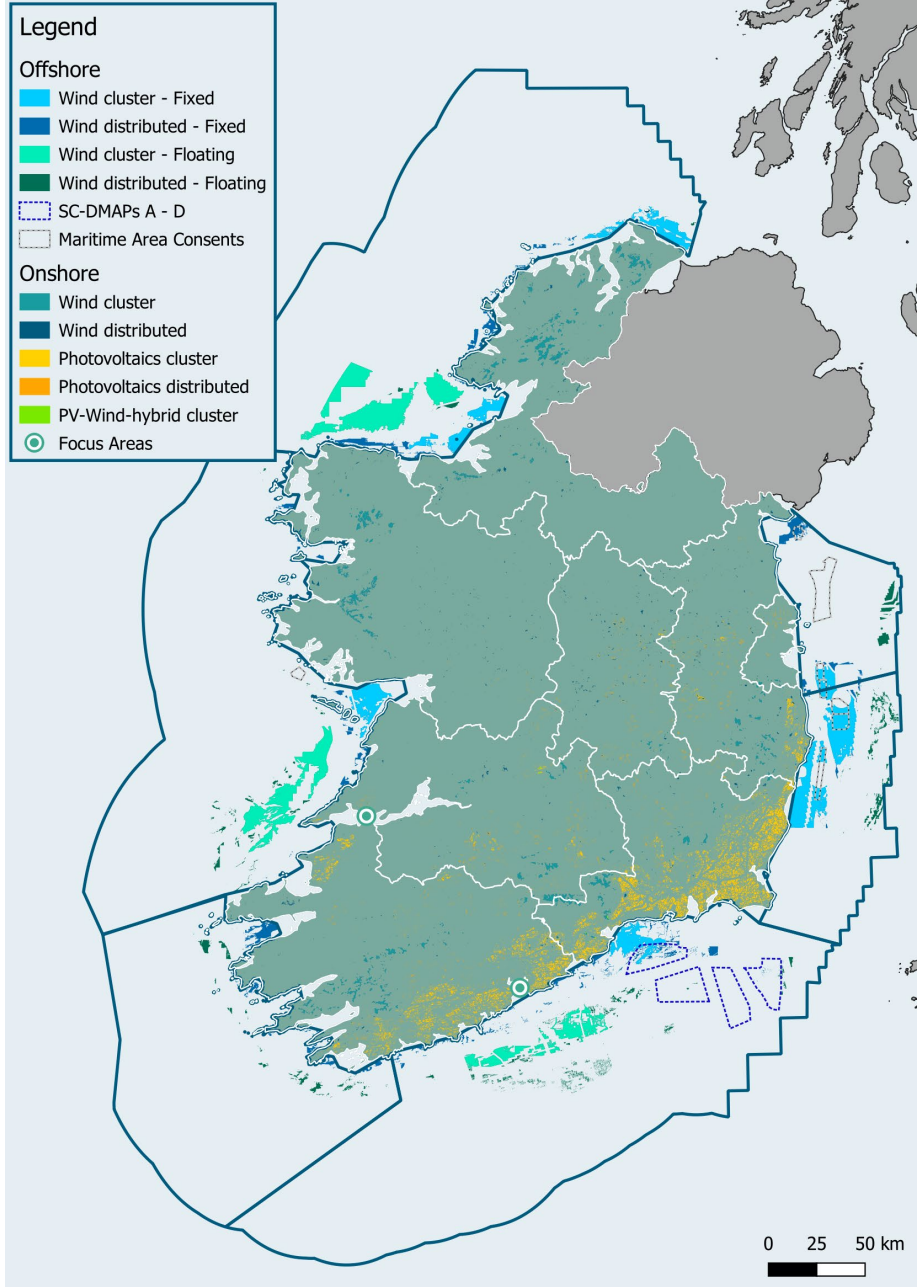
# Results from HYreland

## Production clusters – RE

| KPIs | Unit | OFWC1 | OFWC2 | OFWC3 | OFWC4 | OFWC5 | OFWC6 |
|---|---|---|---|---|---|---|---|
| Area | km² | 478.5 | 380.6 | 227.5 | 224.2 | 225.6 | 227.5 |
| Presence co-location /-usage | - | Partially | Partially | Partially | Partially | No | No |
| Installable capacity | GW | 2.15 | 1.71 | 1.02 | 1.01 | 1.02 | 1.02 |
| Site suitability score | % | 67.3 (62.0 – 75.2) | 69.4 (62.0 – 83.7) | 65.9 (62.0 – 79.6) | 76.0 (62.3 – 85.7) | 64.8 (62.0 – 73.4) | 64.9 (62.0 – 74.1) |
| Net AEP per turbine | GWh/a | 64.0 (60.5 – 66.3) | 64.7 (61.5 – 67.0) | 65.3 (62.2 – 67.1) | 69.1 (68.3 – 70.8) | 69.4 (66.9 – 71.2) | 70.7 (69.4 – 73.4) |
| Average wind speed at 150 m | m/s | 10.15 (9.93 – 10.29) | 10.22 (9.97 – 10.48) | 10.27 (9.69 – 10.43) | 10.77 (10.52 – 11.16) | 10.57 (10.36 – 10.76) | 10.59 (10.00 – 11.05) |
| Monthly power densitiy var. | % | 38.7 (38.2 – 39.1) | 37.9 (36.9 – 38.5) | 38.1 (37.2 – 38.9) | 39.4 (38.1 – 40.5) | 38.1 (37.2 – 38.9) | 39.7 (39.3 – 40.3) |
| Seabed depth | m | -26.5 (-2.2 – -60.0) | -28.0 (-0.9 – -60.0) | -40.9 (-13.1 – -59.4) | -36.9 (-12.4 – -58.6) | -47.2 (-1.6 – -60.0) | -34.1 (-12.0 – -60.0) |
| Dominant seabed composition | | Coarse sediment (Sand) | Coarse sediment (Sand and mixed sediment) | Sand (Coarse sediment) | Mud to sandy mud (Sand) | Sand (Coarse sediment) | Coarse sediment (Unclassified) |
| Distance suitable port | km | Inst: 73 (44 – 93) OM: 20 (10 – 31) | Inst: 58 (32 – 87) OM: 16 (2 – 31) | Inst: 75 (61 – 82) OM: 42 (26 – 58) | Inst: 31 (18 – 46) OM: 19 (8 – 35) | Inst: 283 (251 - 310) OM: 30 (9 – 60) | Inst: 155 (131–196) OM: 148 (131–168) |
| Distance HV-transmission line | km | 20.6 (11.5 – 29.1) | 15.4 (4.6 – 27.8) | 15.0 (4.3 – 25.6) | 32.4 (22.2 – 42.9) | 37.3 (29.1 – 51.7) | 36.6 (30.3 – 45.3) |
| Significant wave height | m | 1.05 (0.85 – 1.21) | 0.90 (0.55 – 1.15) | 1.19 (0.63 – 1.49) | 0.90 (0.36 – 2.07) | 1.74 (0.07 – 2.19) | 1.70 (0.40 – 2.37) |
| LCOE in 2032 | €cent/kWh | 8.33 (8.10 – 8.78) | 8.12 (7.75 – 8.46) | 8.18 (7.68 – 8.47) | 7.62 (7.36 – 7.76) | 7.78 (7.37 – 8.04) | 7.62 (7.22 – 7.82) |

### Identified renewable energy cluster

- Offshore wind – Fixed
  - 6 large-scale clusters with ≥ 1 GW
  - Total cluster area of 1750 km² in line with installation target for 2032 of 8 GW
  - Reasonable fixed offshore wind cluster distribution along the coasts of Ireland
  - Partially overlapping with Maritime Area Consents and SC-DMAP A
- Offshore wind – Floating
  - 3 large-scale clusters with ≥ 1 GW located relatively close to the coast
  - Reasonable floating offshore wind cluster distribution along the western coast
- Onshore wind
  - Limited potential for additional large-scale onshore wind clusters
  - Isolated onshore wind clusters are mainly allocated along western coast, as well as in the north and south of Ireland
- Ground-mounted solar PV
  - PV clusters are highly available, but relatively fragmented
  - PV clusters are allocated along southern coast, with isolated distributed suitable areas in the east and center of Ireland




➢ Compilation of KPIs for identified renewable energy clusters

➢ Input for $H_2$ and PtX hub location assessment





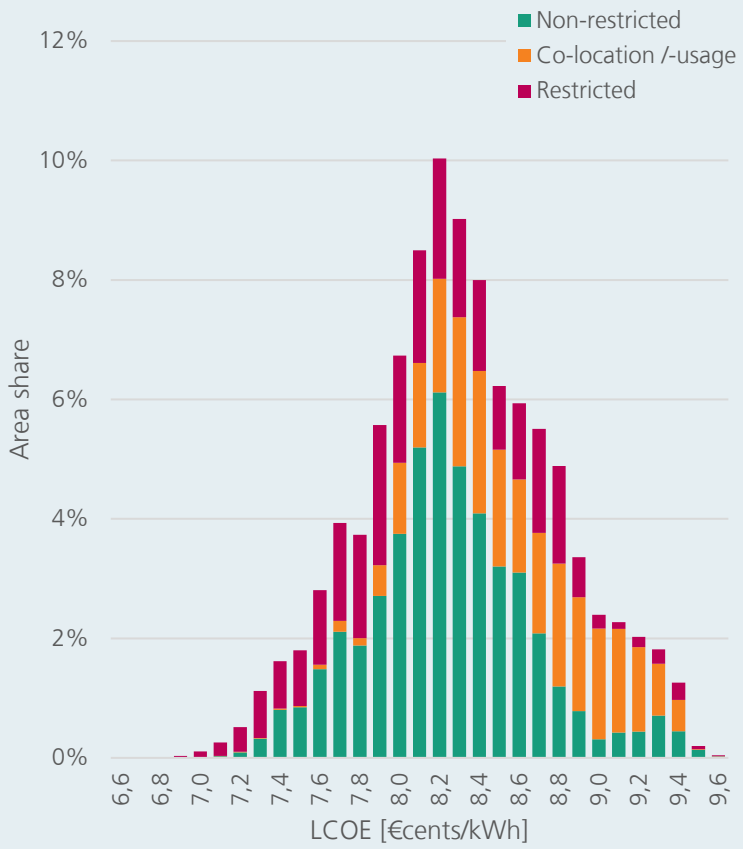
H2 HYreland
Federal Ministry of Education and Research
Funded by the Federal Ministry of Education and Research (FKZ 03SF0788)
Fraunhofer ISE

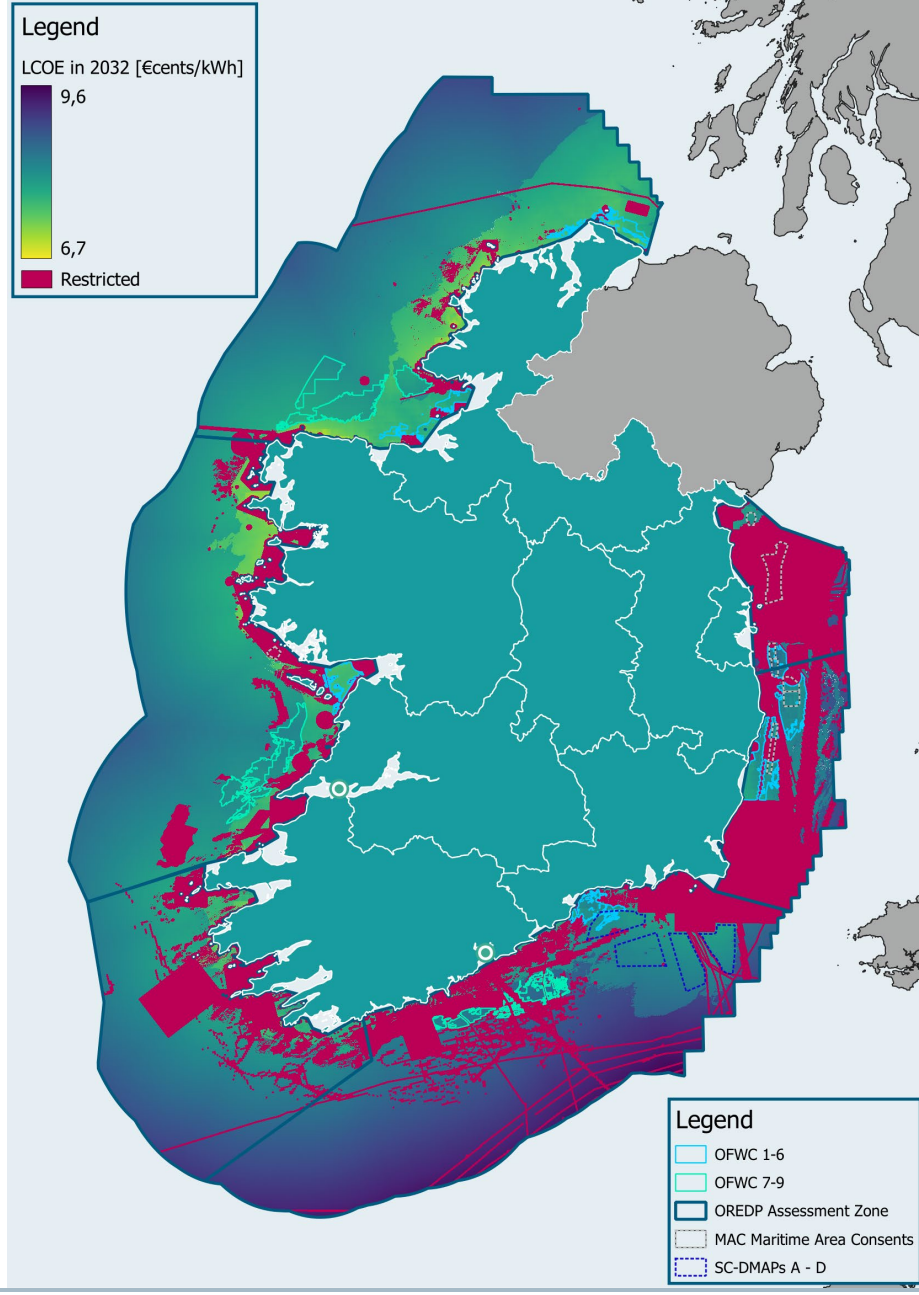
# Results from HYreland

## Levelized cost of electricity – RE

### Levelized cost of electricity – Offshore wind in 2032

- **Spatially-resolved LCOE analysis** for a **1 GW offshore wind park** with 15 MW turbines **in 2032**
- Component-based learning rates to enable future cost projections
- LCOE affected by **annual electricity production, foundation type, seabed depth, as well as the distance to shore, installation & OM ports**







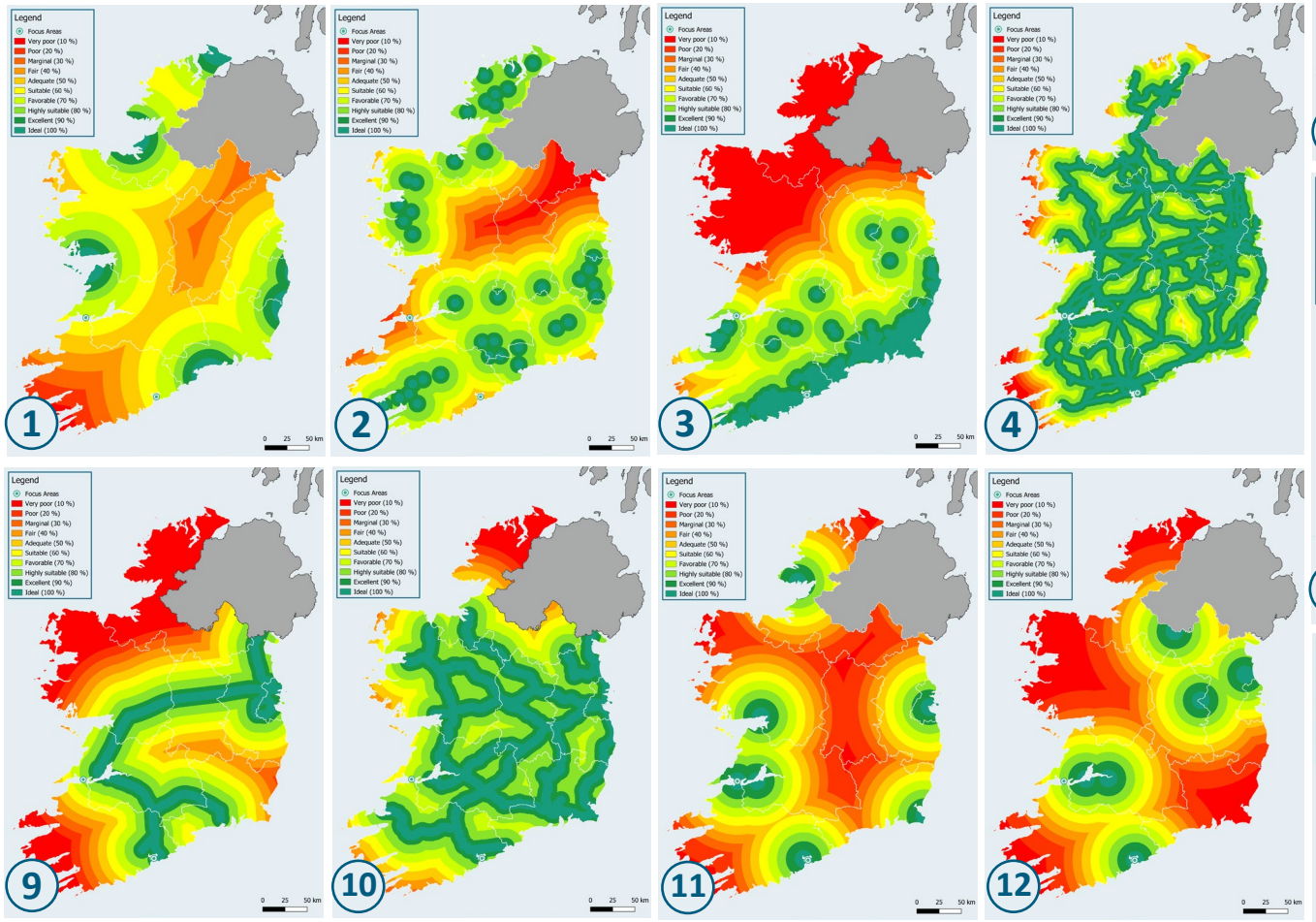

H2 HYreland
Federal Ministry of Education and Research
Funded by the Federal Ministry of Education and Research (FKZ 03SF0788)
Fraunhofer ISE

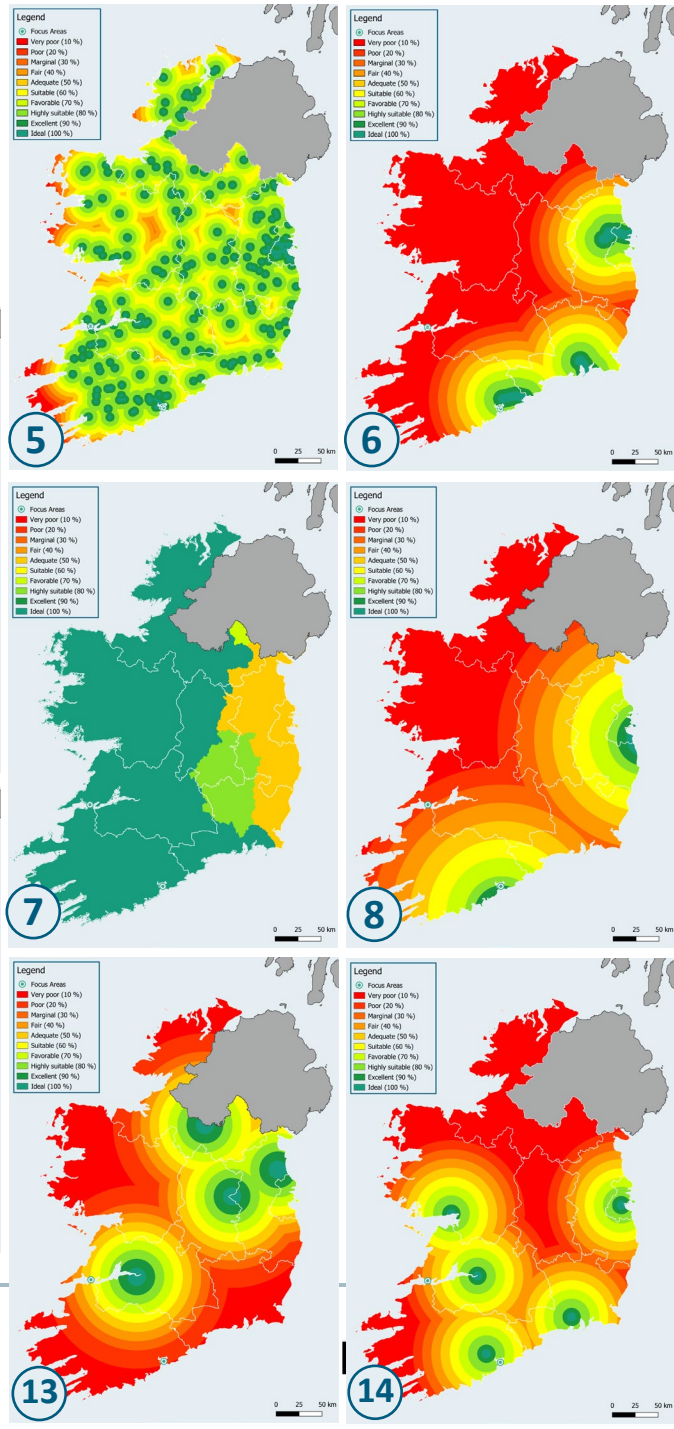
# Results from HYreland

## Suitability criteria – Power-to-Hydrogen and Power-to-SAF

### Power-to-Hydrogen

1 Offshore wind clusters
2 Onshore wind clusters
3 Ground-mounted PV clusters
4 HV-transmission lines
5 HV-substations
6 Electricity interconnectors
7 Water stress
8 Underground $H_2$ storage
9 Potential future $H_2$ pipelines
10 Railways
11 Seaports
12 Local $H_2$ offtake
13 Local $O_2$ offtake
14 Local heat offtake








H2 HYreland
Federal Ministry of Education and Research
Funded by the Federal Ministry of Education and Research (FKZ 03SF0788)

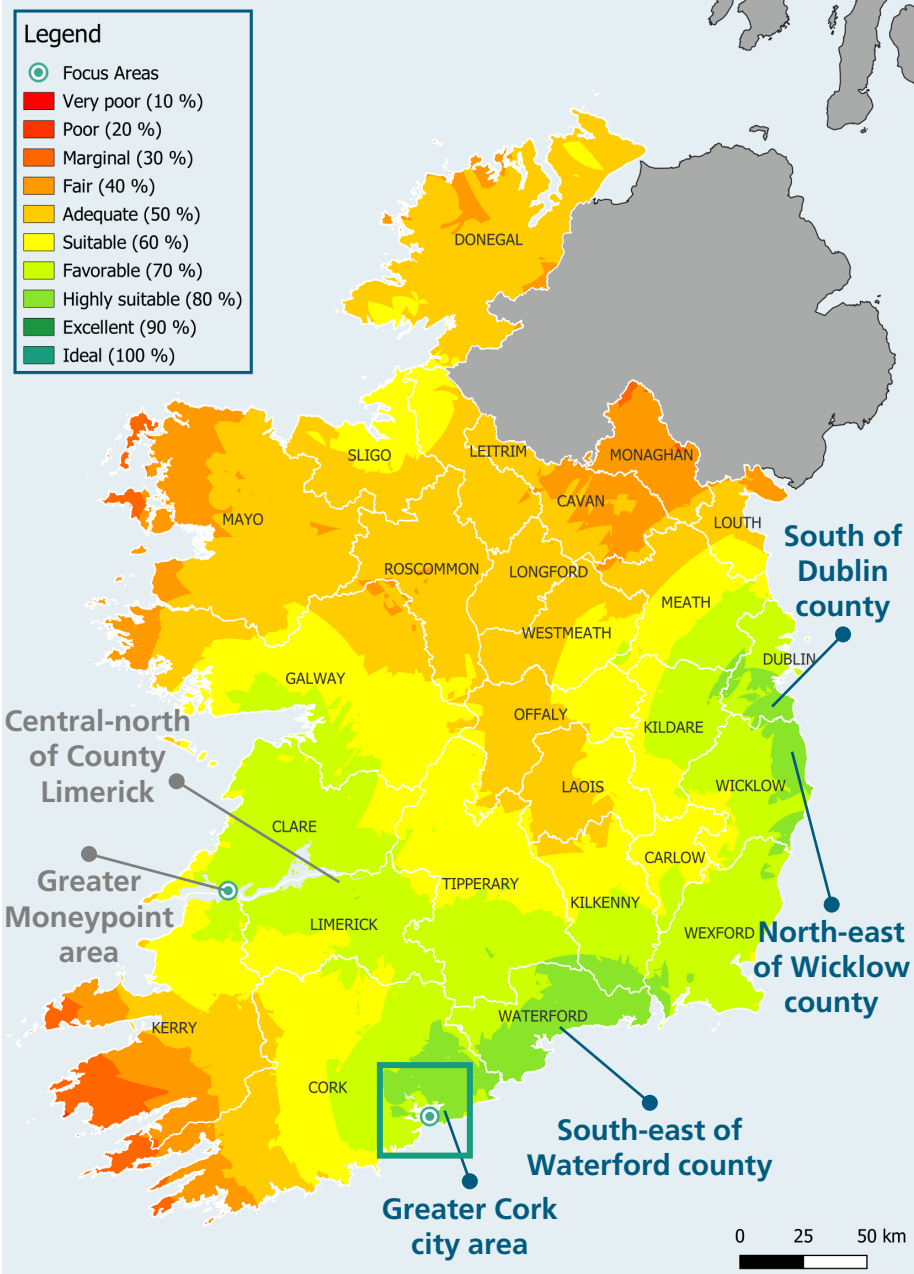
# Results from HYreland

## Site suitability and production clusters – Power-to-Hydrogen

### Power-to-Hydrogen suitability in Ireland

- Focus on locations suitable for large-scale hydrogen export via pipeline
- Clear identification of regions with a high site suitability score
  - Greater Cork city area
  - South-east of Waterford county
  - North-east of Wicklow county
  - South of Dublin county
  - Central-north of County Limerick (Power-to-SAF)
  - Greater Moneypoint area (Power-to-Ammonia)
- Identified Power-to-Hydrogen clusters are located in proximity of fix-bottom offshore wind clusters and SC-DMAPs
- Northern half of Ireland & south-western part receive lower site suitability scores
- Detailed assessment of identified Power-to-Hydrogen clusters

| Criteria | Weight |
|---|---|
| Offshore wind clusters | 30% |
| Onshore wind clusters | 8% |
| Ground-mounted PV clusters | 15% |
| HV-transmission lines | 3% |
| HV-substations | 4% |
| Electricity interconnectors | 2% |
| Water stress | 5% |
| Underground $H_2$ storage | 8% |
| Potential future $H_2$ pipelines | 10% |
| Railways | 3% |
| Seaports | 6% |
| Local $H_2$ offtake | 2% |
| Local $O_2$ offtake | 1% |
| Local heat offtake | 2% |








HYreland
Federal Ministry of Education and Research
Funded by the Federal Ministry of Education and Research (FKZ 03SF0788)
Fraunhofer ISE

# Results from HYreland

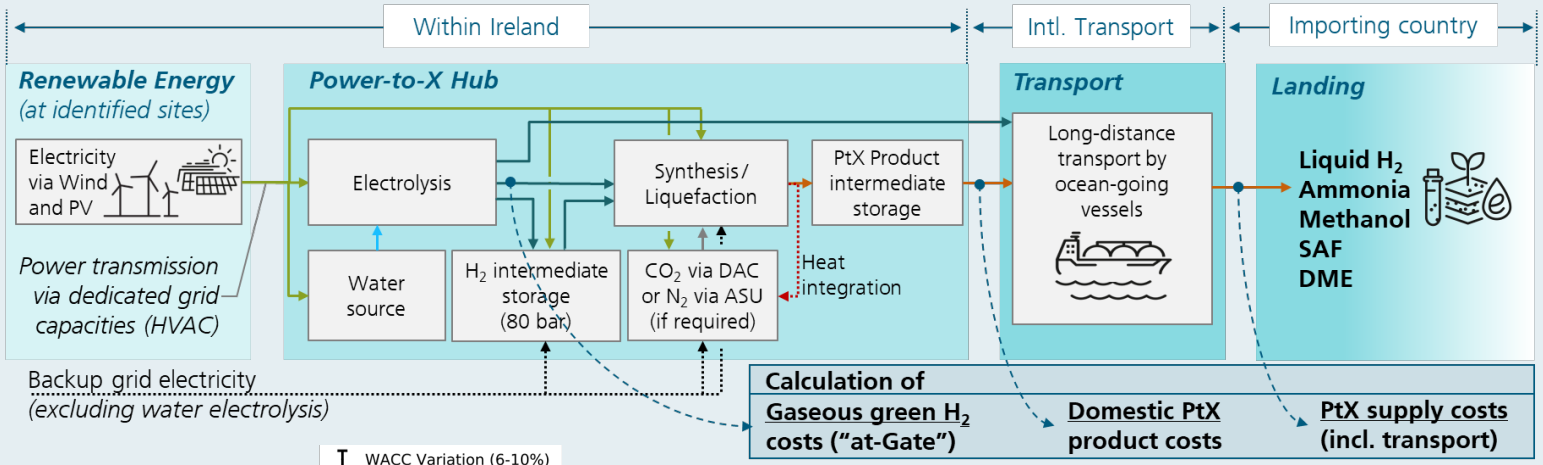
## Site selection – Greater Cork city area

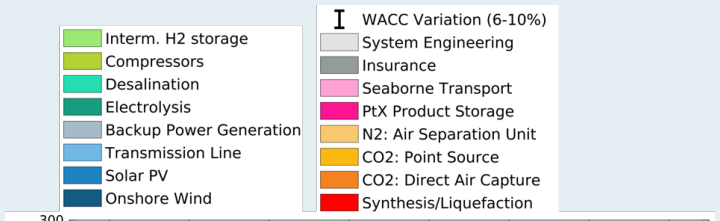
### Large-scale Power-to-X

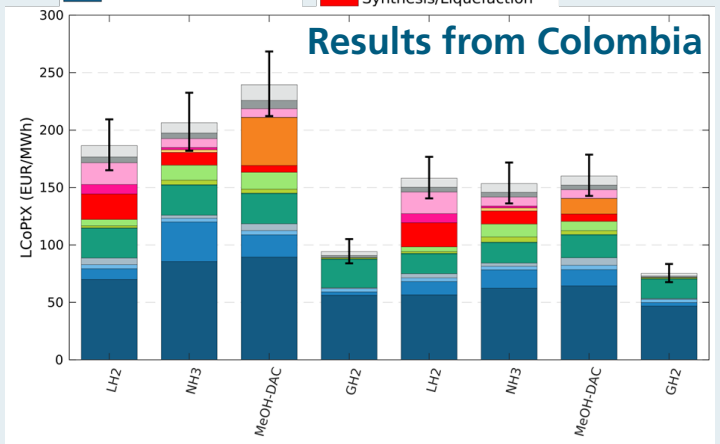
- Focus products: Hydrogen & SAF (MeOH, DME & $NH_3$)
- ⊕ Excellent access to renewable energy
  - Proximity to large-scale fixed and floating offshore wind clusters, in addition to SC-DMAPs
  - Outstanding availability of future PV clusters
  - Reasonable distance to large-scale onshore wind clusters
- ⊕ Access to potential future $H_2$ transmission pipeline system & UHS in depleted gas fields
- ⊕ Access to diverse port facilities & refinery infrastructure
- ⊕ Potential for local hydrogen and SAF offtake
- ⊕ Well-developed HV-transmission grid
- ✓ Limited availability of industrial carbon point sources, but proximity to medium-scale biogenic source
- ✓ Water availability from upgraded water treatment plants, treated wastewater and surface water
- ✓ Limited potential options for heat & oxygen offtake
- ✓ Moderate environmental sensitivity might impede the production and export of specific PtX products (e.g. $NH_3$)

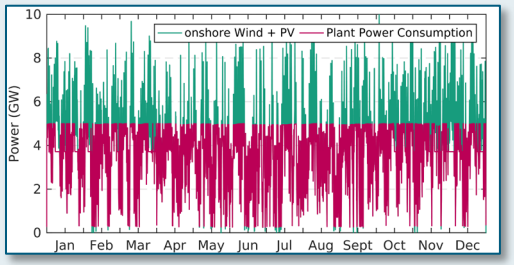
➢ **Excellent location for first-mover $H_2$ & SAF-projects**
➢ **Potential for $H_2$ scale-up & pipeline export**

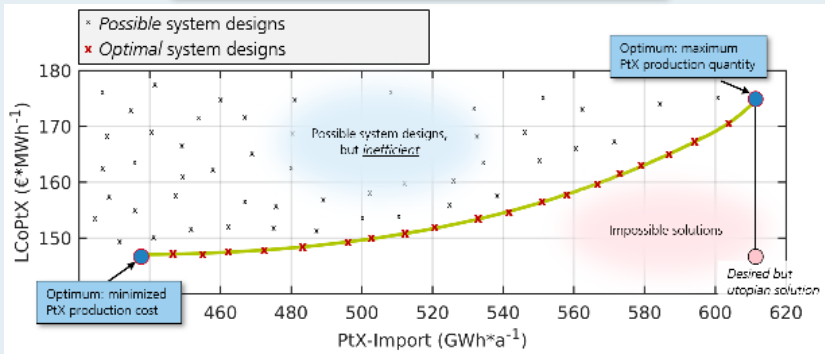
### Dynamic hourly-resolved system optimization of the complete supply chain




➢ Identification of potential PtX supply chain options
➢ Compilation of site-specific techno-economic parameters




H2 HYreland
Federal Ministry of Education and Research
Funded by the Federal Ministry of Education and Research (FKZ 03SF0788)
Fraunhofer ISE

# Wrap-Up and Outlook

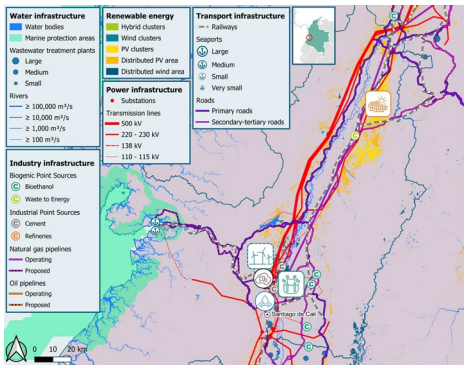
GIS-based site suitability assessments for RE, $H_2$ and PtX

# Recent Reports and upcoming Research

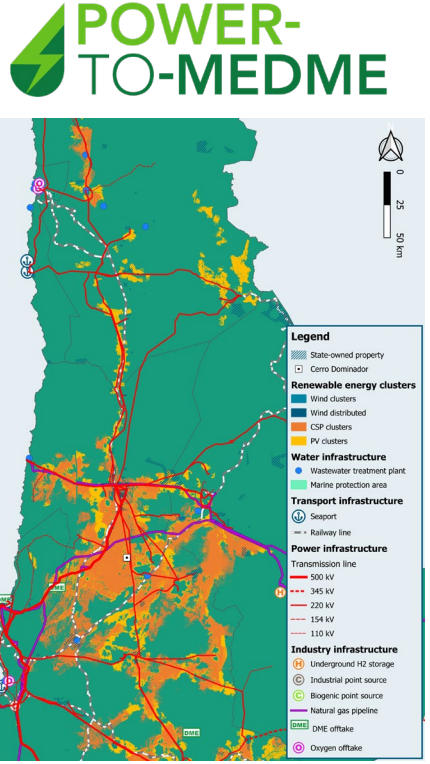
Click on publication to open

- **Selected articles and upcoming reads from our latest research:**

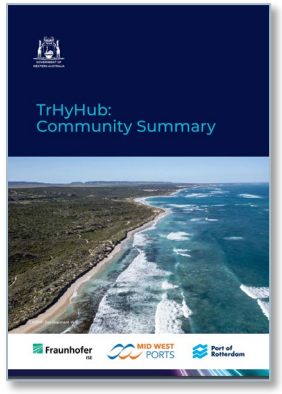
## Power-to-X Colombia

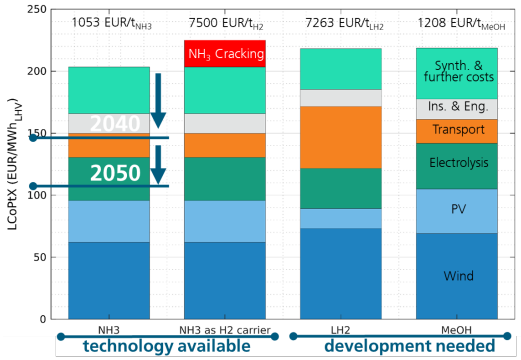




## Power-to-MEDME (Chile)

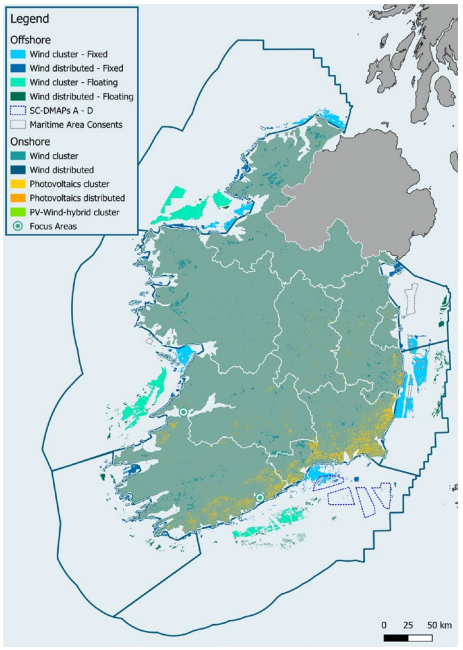



## TrHyHub (Australia)




## HYreland (Ireland)








Fraunhofer ISE


Fraunhofer ISE


## Christoph Hank

christoph.hank@ise.fraunhofer.de

Head of Team System Analysis and Assessment




## Marius Holst

marius.holst@ise.fraunhofer.de

Head of Group Hydrogen Infrastructure and Technical System Analysis




## Lucas Edenhofer

Lucas.edenhofer@ise.fraunhofer.de

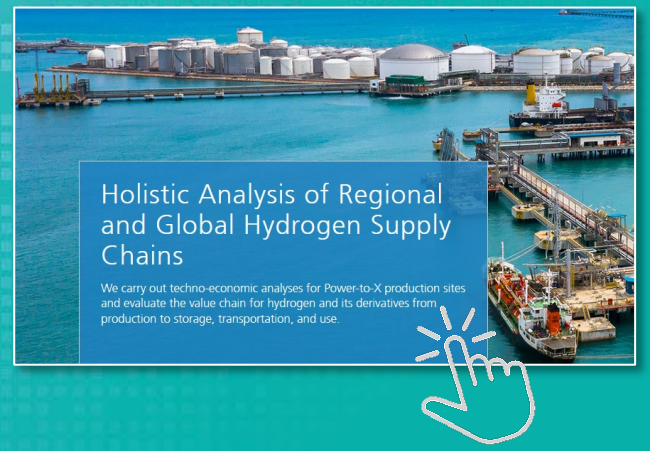
Team System Analysis and Assessment




## Robert Szolak

Robert.szolak@ise.fraunhofer.de

Head of Department Sustainable Synthesis Products



Fraunhofer Institute for Solar Energy Systems ISE, 79110 Freiburg, Germany, www.ise.fraunhofer.de