# Einsatz von grünem Wasserstoff für netzferne Stromversogrung

AHK Chile


Cámara Chileno-Alemana de Comercio e Industria-CAMCHAL
Deutsch-Chilenische Industrie- und Handelskammer

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- Stakeholder und Durchführer

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NOW
Nationale Organisation
Wasserstoff- und Brennstoffzellentechnologie

Ministerio de Energía
Gobierno de Chile

RLI
REINER LEMOINE INSTITUT

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Cámara Chileno-Alemana
de Comercio e Industria-CAMCHAL
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- **Projektziele:**
  - Analyse des Potenzials zum Einsatz von grünem Wasserstoff bei netzfernen Anwendungen
  - Unterstützung des Ziels den Zugang zu Energiedienstleistungen für alle Chilenen zu garantieren
  - Dekarbonisierung der über Dieselgeneratoren vielfach dezentral versorgten Netze
  - SDGs:
    - *Ensure access to affordable, reliable, sustainable and modern energy for all*
    - *Reduce inequalities in electricity supply*

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- Projekt Phasen:
  - 1. Ausarbeitung einer Studie — 08/2021



  - 2. Roundtable — 07/09/2021
  - 3. Fachforum — 05/10/2021


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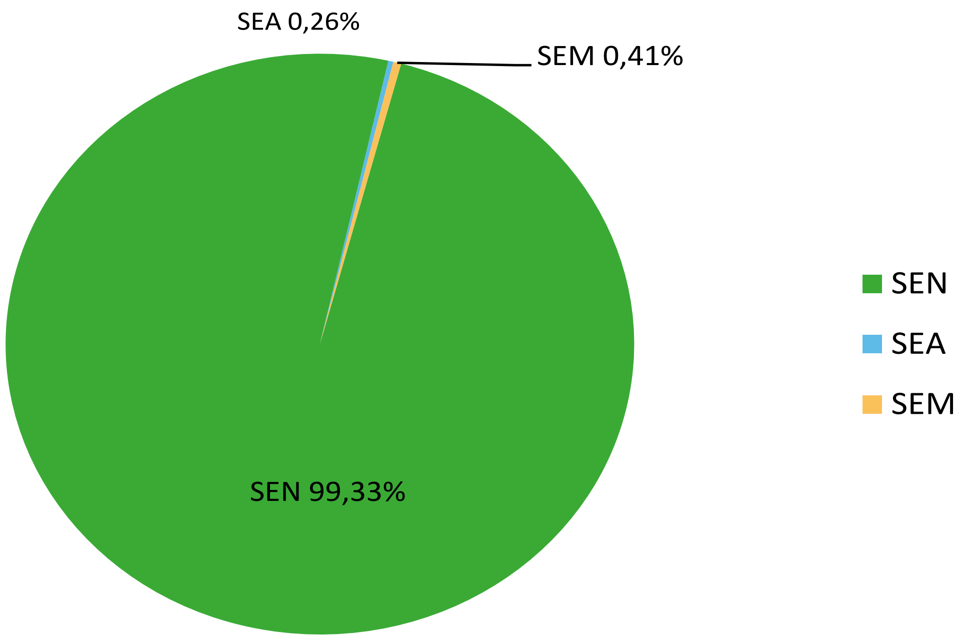
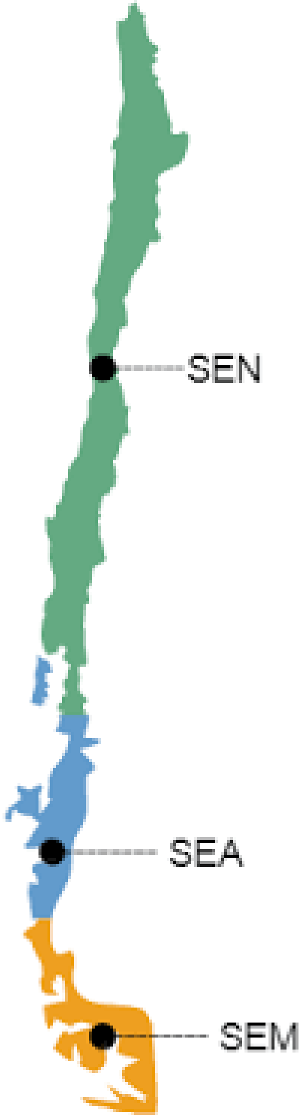
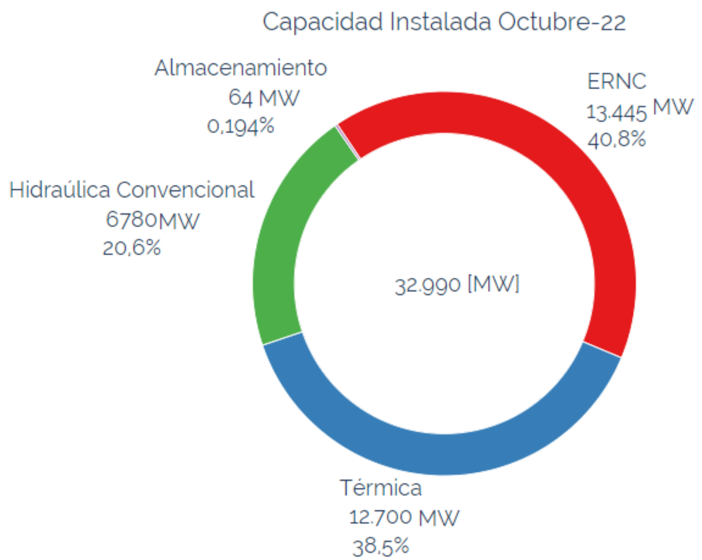
## Stromnetze in Chile




Installierte Gesamtleistung 25.977,33 MW




Considera Sistema Eléctrico Nacional, de Aysén, de Magallanes y de Isla de Pascua. Incluye centrales en operación y en pruebas.

ACERA

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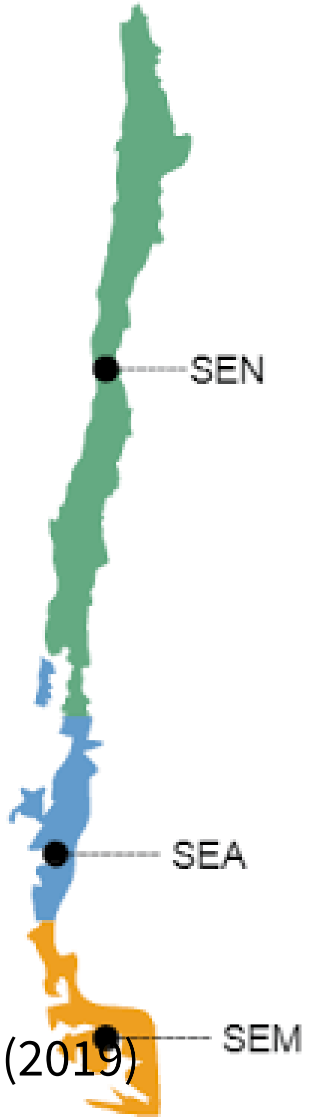
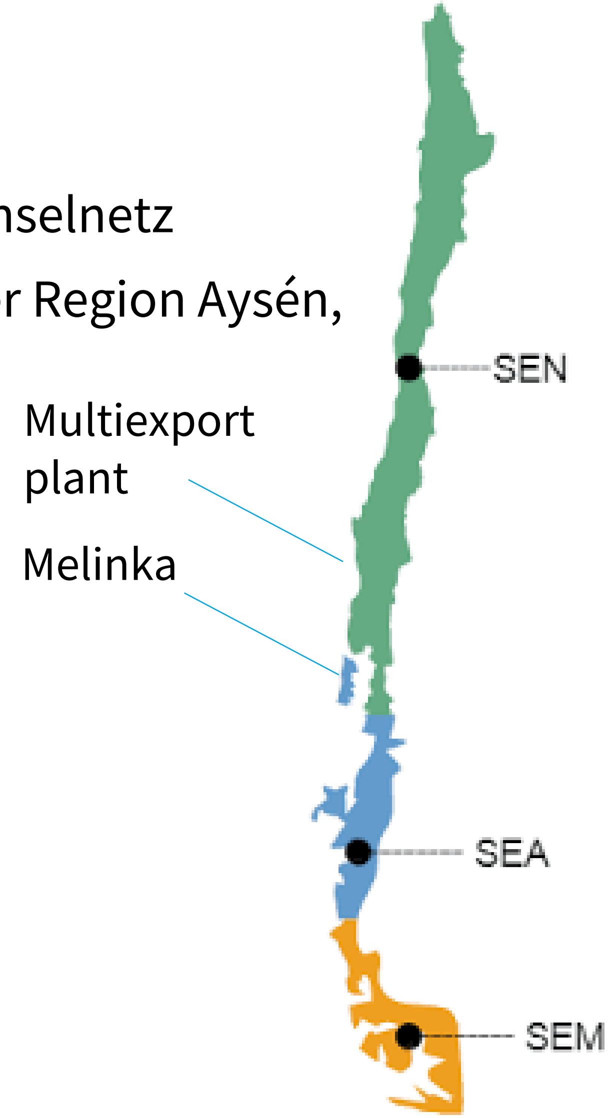
- **Mittlere Stromnetze:**
  - 9 mittlere Stromnetze mit einer Leistung zwischen 1,5 MW und 200 MW
  - 7 von den Netzen in den Regionen Aysén und Magallanes

- **Kleine Stromnetze:**
  - Unter 1,5 MW installierter Leistung
  - 129 kleine Netze, 57 mit 24-hour-supply, 72 mit part-time supply
  - 15.708 Haushalte
- **Selbstversorger:** 2.496 Systeme
- **Ohne Stromanschluss:** 24.556 Haushalte, 6.637 mit einem Stromerzeugungsprojekt (2019)



# Projekt: Einsatz von grünem Wasserstoff für netzferne Stromversogrung

- **Melinka** 1,4 MW: ca. 1.400 Einwohnern und einem ausschließlich mit Dieselgeneratoren betriebenen Stromnetz als Inselnetz
- **System Aysén** 53 MW: Teilnetz des eigenständigen Stromnetzes in der Region Aysén, die ca. 100.000 Einwohner hat
- **Multiexport** 742,5 kW: Fischzuchtbetrieb Molino de Oro

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- Der Multi Vector Simulator (MVS) ist ein Simulationstool, um Energiesysteme mit mehreren Vektoren, also sektorgekoppelte Systeme, zu simulieren und zu optimieren.
- Durchführung einer techno-ökonomischen Optimierung, welche die jährlichen Kosten zur Energiebereitstellung minimiert (Langzeit-Investitionsplanung als auch eine Langzeit- Betriebsplanung)
- Resultat: Optimale Kapazitäten des Energiesystems sowie dem Einsatz der einzelnen Komponenten, als auch einer Berechnung der technischen und ökonomischen Betriebskennzahlen.

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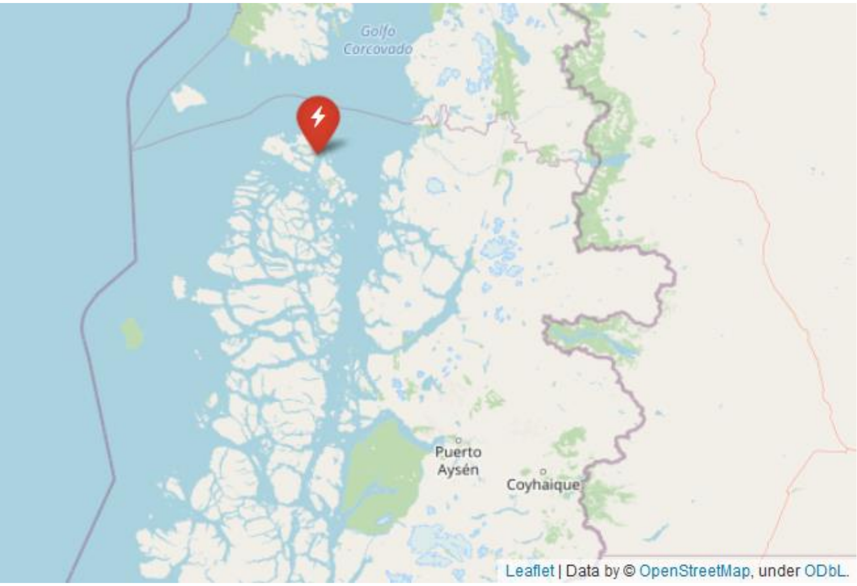
- Melinka:




| Konsument und Empfänger der Subventionen | Anzahl | Durchschnittlicher Stromverbrauch pro Konsument pro Monat (kWh/Monat) | Gesamtstromverbrauch (kWh/Jahr) |
|---|---|---|---|
| Haushalte | 631 | 119 | 902.295 |
| Schulen | 5 | 437 | 26.248 |
| Postamt | 1 | 1.269 | 15.222 |
| Öffentliche Einrichtungen | 56 | 370 | 248.862 |
| Kirchen | 5 | 27 | 1.591 |
| Lebensmittelläden | 30 | 404 | 145.619 |
| Sonstige (Gaststätten, Kneipen, Pensionen) | 35 | 311 | 130.803 |
| Sonstige (Märkte, Fischindustrie) | 11 | 148 | 19.550 |
| Strassenbeleuchtung | 1 | 14.204 | 170.452 |

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- Melinka:

| Scenarios / Assets | Diesel only (status quo) [ I ] | Diesel capacity optimized ($H_2$ storage) [ II ] | Diesel capacity optimized (combined storages) [ III ] |
|---|---|---|---|
| **Diesel generator** | Existing capacity | Optimized | Optimized |
| **PV** | -/- | Optimized | Optimized |
| **Wind turbine** | -/- | Optimized | Optimized |
| **Electrolyzer** | -/- | Optimized | Optimized |
| **Fuel cell** | -/- | Optimized | Optimized |
| **H2 storage** | -/- | Optimized | Optimized |
| **Li-ion storage** | -/- | -/- | Optimized |

fuel price:
1.07 USD/kWh

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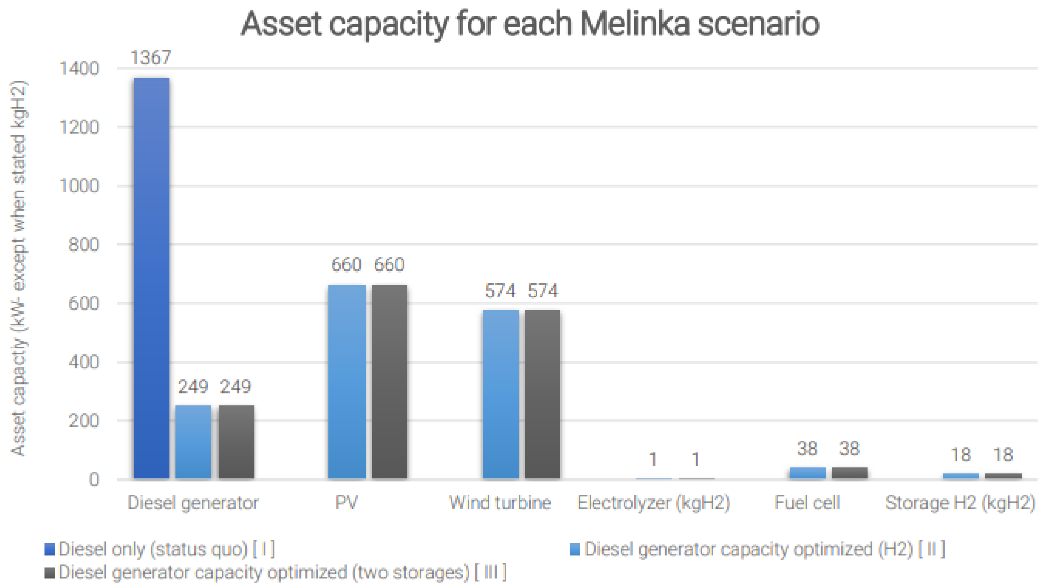
- Melinka: Vergleich der Szenarien und KPIs




No Li-ion battery is installed in scenario [III] as H2 is more economically viable, this makes scenarios [II] and [III] completely identical

| Scenarios / Parameters | Diesel only (status quo) [ I ] | Diesel capacity optimized (combined storages) [ III ] |
|---|---|---|
| LCOE (Levelized costs of electricity supply) (USD/kWh) | 0.3057 | 0.1302 |
| NPV (net present value) (M USD) | 3.86 | 1.65 |
| Upfront investment (M USD) | 0.00 | 1.51 |
| Annual O&M costs (USD/a) | 507 698 | 85 057 |
| Diesel consumption (L/a) | 474 469 | 58 658 |
| Renewable factor (%) | 0 | 79 |
| Emissions ($T_{CO2,eq}$/a) | 1281 | 158 |
| Required subsidy (USD/a) | 422 042 | 162 258 |
| Actual electricity price (USD/kWh) | 0.46 | 0.28 |

- Scenario [ I ] represents status quo. Its actual electricity price (LCOE plus fix management costs) is with 0.46 USD/kWh close to the quoted 0.51 USD/kWh
- Scenario II and III are identical, as no Li-Ion storage installed. Both require less subsidies then the current system!
- Installing H2 for storage of electricity results in lower LCOE, annual O&M, diesel consumption, subsidies
- As most systems with high renewable factors, upfront investment costs are very high but could be paid off with saved subsidies in 8 years!
- Scenario III results in 23% unused excess generation. Re-assessing Li-Ion battery costs beneficial.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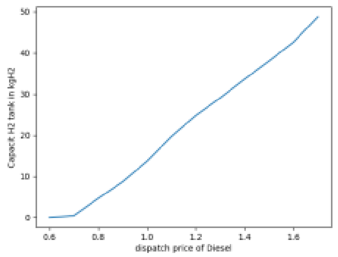
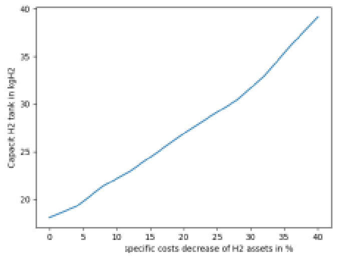
- Melinka: Análisis de Sensibilidad

| System / Factor variation | Melinka (two storages) [III] |
| --- | --- |
| Diesel price (USD/L) | 0.6 - 1.6<br>i = 0.1 |
| Base diesel price (USD/L) | 1.07 |
| H2 assets costs decrease (%) | 0 – 40<br>i = 4 |
| Base H2 asset costs | H2 tank: 2297 (USD/kgH2)<br>Electrolyzer: 750 (USD/kW)<br>Fuel cell: 700 (USD/kW) |

- The H2 assets price decrease was based on the Planned Energy Scenario from IRENA which describes a cost reduction of 40% by 2030 *.

* IRENA (2020), Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5ºC Climate Goal, International Renewable Energy Agency, Abu Dhabi.




### Diesel price sensitivity

- The overall LCOE raises with increasing diesel fuel price. Diesel fuel expenses rise until 0.7 USD/L and then decline, as they are replaced by renewables.
- Up until a renewable factor of 65% at a diesel price of 0.7 USD/L no hydrogen assets are installed
- With a diesel price > 0.7 USD/L, the installation and use of hydrogen assets becomes economically viable

### Hydrogen learning curve sensitivity

- Decreasing H2 asset costs directly influence the capacity that is installed at site.
- The share of renewable follows the trend of the H2 tank capacity

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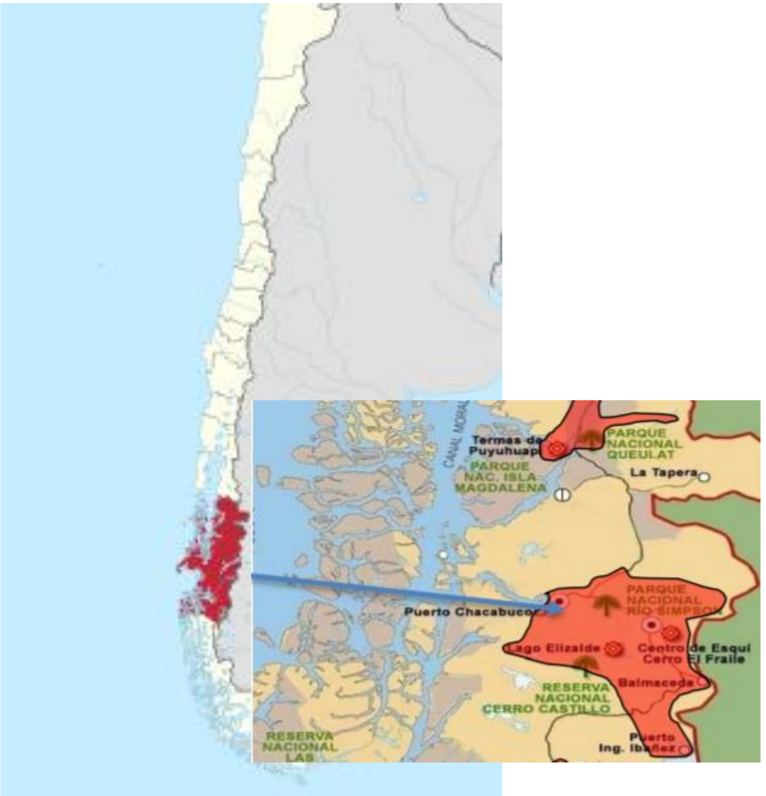
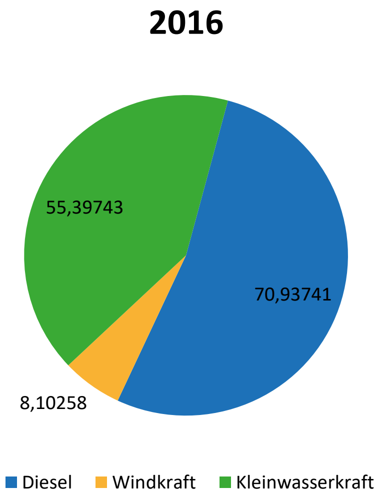
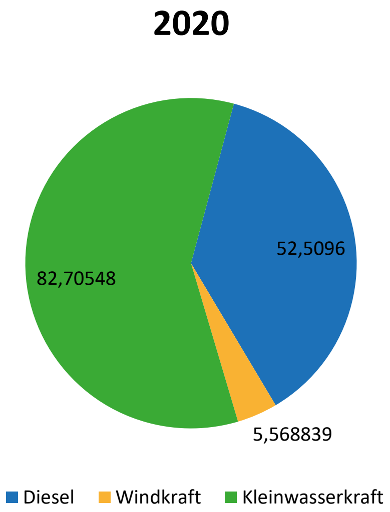
- Aysén:




- Existing diesel generator
- Existing run-off-river hydro power stations
- Existing Wind power
- No subsidies
- Goal: Find optimal PV, Wind and H2 capacities

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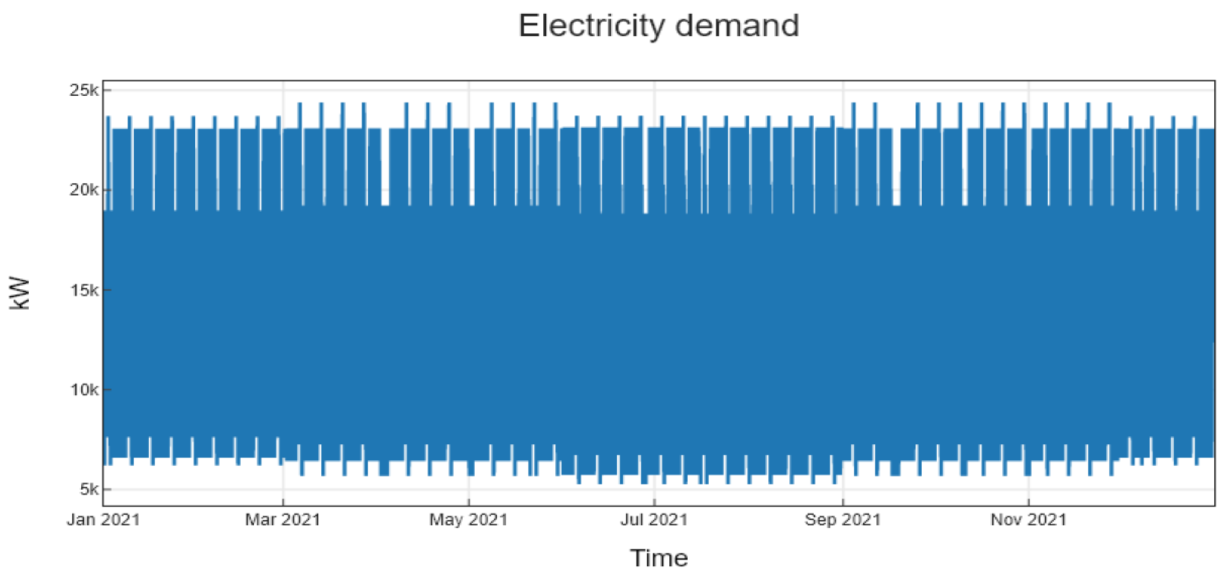
- Aysén:




Wie bereits für Melinka aufgezeigt, werden hier sowohl die chilenische Jahreszeitenabhängigkeit, als auch Feiertage und Wochenenden berücksichtigt. Es zeigt sich eine geringere Jahreszeitenabhängigkeit als in Melinka. Es ergibt sich einjährlicher Verbrauch von 131 GWh/Jahr, bei einer Maximallast von 24,4 MW

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- Aysén:

| Assets \ Scenarios | Hydro, wind and diesel (status quo) [ I ] | Hydro capacity set (H2 storage) [ II ] | Hydro capacity set (combined storages) [ III ] |
|---|---|---|---|
| **Diesel generator** | Existing capacity | Optimized | Optimized |
| **PV** | -/- | Optimized | Optimized |
| **Wind turbine** | Existing capacity | Optimized | Optimized |
| **Hydro power** | Existing capacity | Existing capacity | Existing capacity |
| **Electrolyzer** | -/- | Optimized | Optimized |
| **Fuel cell** | -/- | Optimized | Optimized |
| **H2 storage** | -/- | Optimized | Optimized |
| **Li-ion storage** | -/- | -/- | Optimized |

fuel price: 0.64 USD/L, including special tax

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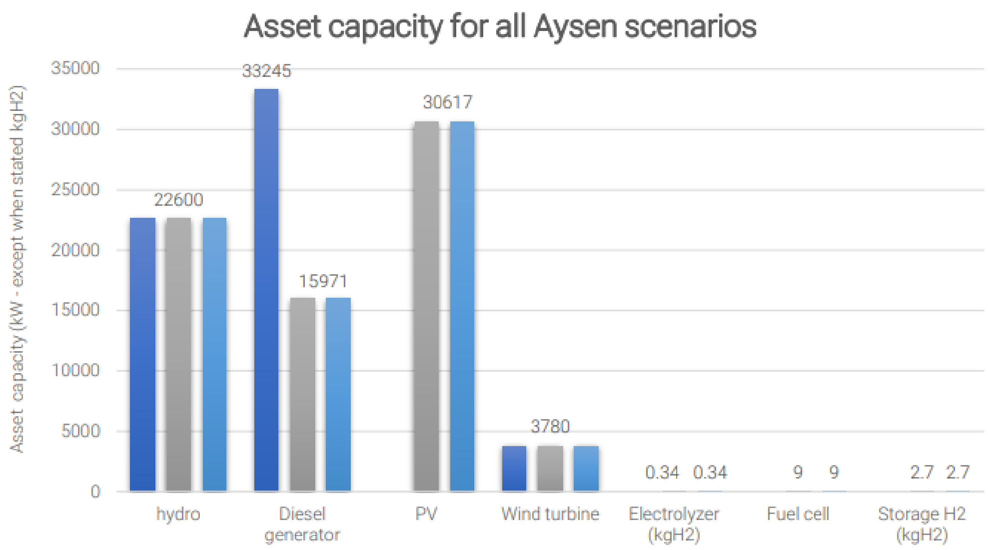
- Aysén: Vergleich der Szenarien und KPIs




- Replacing diesel generator though renewables is cost-effective: 30 MWp PV
- Scenario [ II ] and [ III ] have no Li-ion storage installed and are therefore identical

| Parameters / Scenarios | Hydro, wind and diesel (status quo) [ I ] | Hydro capacity set (combined storages) [ III ] |
|---|---|---|
| LCOE (Levelized costs of electricity supply) (USD/kWh) | 0.0674 | 0.0443 |
| NPV (net present value) (M USD) | 67.15 | 44.08 |
| Upfront investment (M USD) | 0.00 | 21.46 |
| Annual O&M costs (M USD/a) | 8 822 913 | 4 100 071 |
| Diesel consumption (L/a) | 13 602 085 | 6 221 162 |
| Renewable factor (%) | 42 | 69 |
| Emissions ($T_{co2}$/a) | 36 726 | 16 797 |

- LCOE of the supply can be decreased by installing PV
- Would increase renewable share from 42% to 69%
- Decreases diesel consumption and CO2 emissions by more than half
- Excess generation in I 10%, in II/III 17%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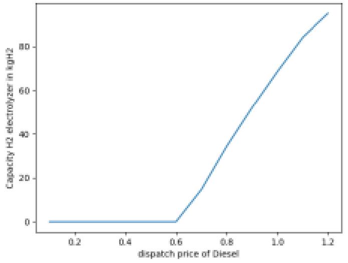
# Projekt: Einsatz von grünem Wasserstoff für netzferne Stromversogrung

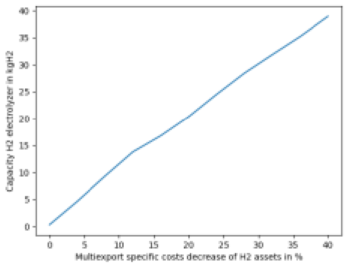
- Aysén: Sensitivity analysis

| System / Factor variation | Aysen (two storages) [III] |
| --- | --- |
| **Diesel price (USD/L)** | 0.1 - 1.1<br>i = 0.1 |
| Base diesel price (USD/L) | 0.64 |
| **H2 assets costs decrease (%)** | 0 – 40<br>i = 4 |
| Base H2 asset costs | H2 tank: 2297 (USD/kgH2)<br>Electrolyzer: 750 (USD/kW)<br>Fuel cell: 700 (USD/kW) |

- The H2 assets price decrease was based on the Planned Energy Scenario from IRENA which describes a cost reduction of 40% by 2030 *.

* IRENA (2020), Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5ºC Climate Goal, International Renewable Energy Agency, Abu Dhabi.




### Diesel price sensitivity

- At a diesel price > 0.6 USD / L, the installation and use of hydrogen assets becomes economically viable
- Current system with renewable factor of 70% is a tipping point – slight fuel price increases will result in much higher H2 capacity
- With a diesel price > 1.1 USD / L, the installation and use of lithium-ion storage becomes economically viable

### Hydrogen learning curve sensitivity

- Decreasing H2 tank costs directly influence the capacity that is installed at site, especially as Aysen is currently at a tipping point
- The share of renewable follows the trend of the H2 tank capacity

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- **Multiexport:**


Die Stromversorgung wird durch drei Dieselgeneratoren sichergestellt, die abwechselnd betrieben werden: 297 kW, 247,5 kW und 198 kW. Außerdem besteht ein Sauerstoffkonsum, der Sauerstoff wird zurzeit durch einen externen Dienstleister bereitgestellt. Die mögliche Kostenreduzierung durch die Verwendung des bei der Elektrolyse anfallenden Sauerstoffs konnte hier in der Simulation nicht berücksichtigt werden, da keine stunden oder tagesgenaue Daten für den Sauerstoffkonsum vorlagen.

Lastprofil: Über den Tag nur sehr geringen Schwankungen und bleibt immer nah bei 40 kW. Für das Tageslastprofil wurden Strommessungen, die über den Zeitraum von 24 Stunden aufgenommen wurden, bei einer Betriebsspannung von drei-phasigen 380 V, berücksichtigt.

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- Multiexport:

| Scenarios / Assets | Diesel only (status quo) [ I ] | Diesel capacity optimized (H2 storage) [ II ] | Diesel capacity optimized (combined storages) [ III ] |
|---|---|---|---|
| Diesel generator | Existing capacity | Optimized | Optimized |
| PV | -/- | Optimized | Optimized |
| Electrolyzer | -/- | Optimized | Optimized |
| Fuel cell | -/- | Optimized | Optimized |
| H2 storage | -/- | Optimized | Optimized |
| Li-ion storage | -/- | -/- | Optimized |

fuel price confidential

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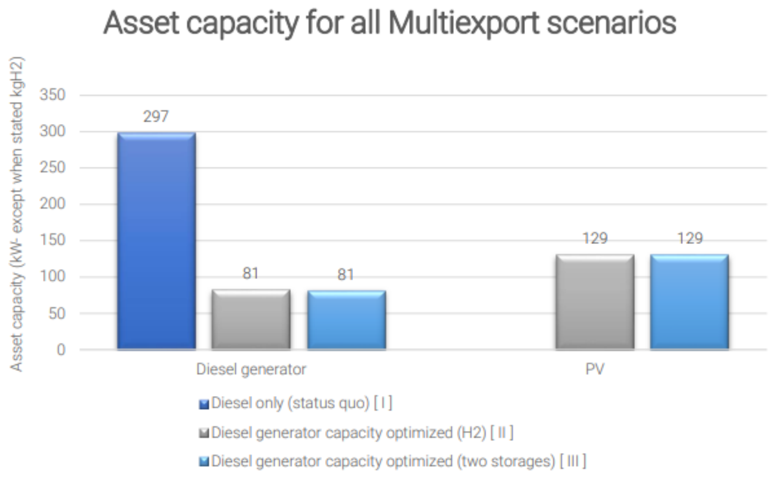
# Projekt: Einsatz von grünem Wasserstoff für netzferne Stromversogrung

- Multipexport: Vergleich der Szenarien und KPIs




- Scenario [ II ] and [ III ] have no H2 assets installed
- Scenario [ III ] has no lithium-ion storage installed which makes it identical to scenario [ II ]

| Parameters / Scenarios | Diesel only (status quo) [ I ] | Diesel capacity optimized (combined storages) [ III ] |
|---|---|---|
| LCOE (Levelized costs of electricity supply) (USD/kWh) | 0.14 | 0.12 |
| NPV (net present value) (USD) | 433,772 | 372,573 |
| Upfront investment (USD) | 0 | 90,533 |
| Annual O&M costs (USD/a) | 56,997 | 40,608 |
| Diesel consumption (L/a) | 116,312 | 82,872 |
| Renewable factor (%) | 0 | 15,7 |
| Emissions ($T_{co2}$/a) | 314 | 224 |

- Scenario [ III ] shows a decrease in CO2 emissions and levelized cost of electricity due to the installation of PV
- The diesel generator seems to be partially replacable by PV which is sufficient to feed the demand
- Excess generation high with 19% - a re-evaluation of the Li-Ion battery costs would be beneficial

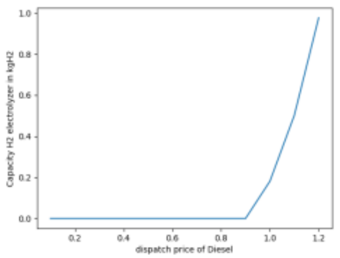
# Projekt: Einsatz von grünem Wasserstoff für netzferne Stromversogrung

- Multiexport: Sensitivity analysis

| System / Factor variation | Multiexport (two storages) [ III ] |
|---|---|
| **Diesel price (USD/L)** | 0.1 – 1.2<br>i = 0.1 |
| Base diesel price (USD/L) | confidential |
| **H2 assets costs decrease (%)** | 0 – 40<br>i = 4 |
| Base H2 asset costs | H2 tank: 2297 (USD/kgH2)<br>Electrolyzer: 750 (USD/kW))<br>Fuel cell: 700 (USD/kW) |

- The H2 assets price decrease was based on the Planned Energy Scenario from IRENA which describes a cost reduction of 40% by 2030 *.

* IRENA (2020), Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5ºC Climate Goal, International Renewable Energy Agency, Abu Dhabi.




### Diesel price sensitivity

- The overall LCOE raises steeply with the diesel price
- With a diesel price >0.9 USD / L at a renewable factor of 20% the installation and use of hydrogen assets becomes economically viable
- Possible CO2 emission pricing could bring about this change in the future
- No Li-ion storage installed even at a diesel price of 1.2 USD / L

### Hydrogen learning curve sensitivity

- Even with 40% costs decrease for all H2 assets, it is not economically optimal to install hydrogen to store excess electricity. (Only at a cost decrease of 96% would H2 assets be installed)
- With the current system, hydrogen installations does not make sense, even if it is almost entirely payed subsidies
- It would be interesting to look at this system knowing the oxygen demand to see if there is a possible trade off with local oxygen production

# Projekt: Einsatz von grünem Wasserstoff für netzferne Stromversogrung

- Empfehlungen

## Melinka

- Recommended capacity: 33 kW electrolyser, 18 kg H2 tank, 38 kW fuel cell, 660 kWp PV, 574 kWp wind
- Decrease LCOE by half
- 1.5 Mill. USD, credit programme necessary
- Saving subsidies can finance this within 8 years

## Aysén

- Recommended capacity: 11.3 kW electrolyser, 2.7 kg H2 tank, 9 kW fuel cell, 30.6 MWp PV
- Currently at tipping point, increasing diesel fuel prices will result in much higher H2 capacities

## Multiexport

- Recommended capacity: 129 kWp PV, no storage
- Hidden potential for H2 and Oxygen co-generation to be investigated

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## Einsatz von grünem Wasserstoff für netzferne Stromversogrung

AHK Chile

AHK Cámara Chileno-Alemana de Comercio e Industria-CAMCHAL
Deutsch-Chilenische Industrie- und Handelskammer

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