Supplementary Information for
Bridging the green hydrogen gap: The role of H2Global in cross-continental hydrogen, ammonia and methanol markets

Alexander Meisinger[a], Lukas Jansen[b], Leon Schumm[a], Anton Achhammer[a], Michael Sterner[a]

[a] *Institute for Energy Networks and Energy Storage, University of Applied Sciences (OTH) Regensburg, Seybothstraße 2, Regensburg, 93053, Germany*
[b] *Fraunhofer IEE, Fraunhofer Institute of Energy Economics and Energy System Technology, Joseph-Beuys-Str. 8, 34117 Kassel, Germany*

Email address: `alexander.meisinger@oth-regensburg.de` (Alexander Meisinger)

Supplementary Items List

Supplementary Methodology: System Overview

Electricity

Supply:
Solar
Rooftop solar
Onshore wind
Offshore wind (fixed-pole/floating, AC/DC-connected)
Hydro reservoirs
Pumped-hydro
Run-of-river
Nuclear
Coal, Lignite, Oil powerplant
Geothermal powerplant
Gas CHP (w/wo CC)
Biomass CHP (w/wo CC)
Gas turbine (OCGT, CCGT)
Methanol turbine (OCGT, CCGT w/wo CC)
Hydrogen turbine
Ammonia turbine (OCGT, CCGT)
Hydrogen fuel cell CHP
Battery discharger
Vehicle-to-grid

Demand:
Industry electricity
Residential electricity
Services electricity
Agriculture electricity
Air-sourced heat pump
Ground-sourced heat pump
Resistive heater
Electric vehicle charger
Battery charger
Pumped-hydro
Hydrogen pipeline (compression)
Direct air capture
Haber-Bosch
Electric air furnace
Direct iron reduction
Distribution grid losses
Transmission grid losses
Methanolisation
Electrolysis

Grids & Storage:
Distribution grid
Transmission grid
Battery storage
Pumped-hydro storage
Electric vehicles

Hydrogen

Supply:
Import
Electrolysis
Steam methane reforming (w/wo CC)
Methanol steam reforming (w/wo CC)
Ammonia cracker
Chlor-alkali electrolysis (exogenous)

Demand:
Industry hydrogen
Fischer-Tropsch
Methanolisation
Haber-Bosch
Hydrogen turbine
Hydrogen fuel cell CHP
Methanol-to-kerosene
Sabatier

Grids & Storage:
New pipelines
Retrofitted pipelines
Storage in salt caverns
Storage in steel tanks

Liquid Hydrocarbons

Supply:
Import
Fossil oil refining
Fischer-Tropsch

Storage:
Hydrocarbon storage

Demand:
Naphtha for industry
Oil for services
Kerosene for aviation
Diesel/gasoline for land transport
Fuel oil for shipping
Diesel for agriculture
Oil for residential

Methanol

Supply:
Import
Methanolisation

Storage:
Hydrocarbon storage

Demand:
Methanol turbine (OCGT, CCGT w/wo CC)
Fuel methanol for shipping
Methanol industry
Methanol-to-kerosene
Methanol steam reforming (w/wo CC)

Methane

Supply:
Import
Fossil gas
Biogas upgrading (w/wo CC)
Sabatier

Storage:
Hydrocarbon storage

Demand:
Industry gas (w/wo CC)
Services gas
Residential gas
Gas boiler (rural/urban)
Gas CHP
Steam methane reforming (w/wo CC)
Gas turbine (OCGT, CCGT)

Ammonia

Supply:
Import
Haber-Bosch

Storage:
Ammonia tank

Demand:
Ammonia industry
Ammonia turbine (OCGT, CCGT)
Ammonia cracker
Ammonia for fertilizer
Fuel ammonia for shipping

Heat

Supply:
Air-sourced heat pump
Ground-sourced heat pump (only rural)
Resistive heater
Gas boiler
Biomass boiler
Solar thermal
Water tank discharger
Biomass CHP (w/wo CC, only DH)
Gas CHP (w/wo CC, only DH)
Hydrogen fuel cell CHP (only DH)
Electrolysis (only DH)
Sabatier (only DH)
Fischer-Tropsch (only DH)
Methanolisation (only DH)

Demand:
Industry heat
Residential heat
Services heat
Agriculture heat
Low-T industry heat
Direct air capture
Water tank charger

Storage:
Long-duration thermal storage (only DH)
Hot water tank

CO_2 atmosphere

Supply:
Kerosene for aviation
Diesel for agriculture
Fuel methanol for shipping
Oil for services
Naphtha for industry
Coal for industry
Diesel/gasoline for land transport
Fuel oil for shipping
Gas boiler
Gas CHP (w/wo CC)
Gas turbine (OCGT, CCGT)
Methanol turbine (OCGT, CCGT w/wo CC)
Process emissions (w/wo CC)
Fossil oil refining
Coal, Lignite, Oil, Biomass powerplant
Industry gas (w/wo CC)
Services gas
Residential gas
Steam methane reforming (w/wo CC)

Demand:
Solid biomass for industry (w CC)
Biomass CHP (w CC)
Biogas upgrading (w CC)
Direct air capture

CO_2 commodity

Supply:
Direct air capture
Biogas upgrading (w CC)
Gas CHP (w CC)
Steam methane reforming (w CC)
Methanol steam reforming (w CC)
Methanol turbine (OCGT, CCGT w CC)
Process emissions (w CC)
Solid biomass for industry (w CC)
Industry gas (w CC)

Demand:
Fischer-Tropsch
Methanolisation
Sequestration
Sabatier

Storage:
Intermediate storage in steel tank
Long-term geological sequestration

Supplementary Figure 1: Overview of the energy system modelling options by carrier in PyPSA-Eur (GreenDeal and Business-as-Usual scenario) for Europe in 2030 and 2050. The structure is based on the scenarios analysed in this research and builds on ref.[1], with modifications by the author. AC = alternating current; DC = direct current; OCGT = open cycle gas turbine; CCGT = combined cycle gas turbine; CHP = combined heat and power; CC = carbon capture; DH = district heating.

Electricity

Supply:
- Solar
- Rooftop solar
- Onshore wind
- Offshore wind (AC/DC-connected)
- Hydro reservoirs
- Pumped-hydro
- Run-of-river
- Nuclear
- Coal, Lignite, Geothermal, Oil, Biomass powerplant
- Gas CHP (w/wo CC)
- Biomass CHP (w/wo CC)
- Gas turbine (OCGT, CCGT)
- Hydrogen fuel cell CHP
- Battery discharger

Demand:
- Industry electricity
- Residential electricity
- Services electricity
- Agriculture electricity
- Air-sourced heat pump
- Ground-sourced heat pump
- Resistive heater
- Electric vehicle charger
- Battery charger
- Pumped-hydro
- Hydrogen pipeline (compression)
- Direct air capture
- Haber-Bosch
- Distribution grid losses
- Transmission grid losses
- Methanolisation
- Electrolysis

Grids & Storage:
- Distribution grid
- Transmission grid
- Battery storage
- Pumped-hydro storage
- Electric vehicles

Hydrogen

Supply:
- Import
- Electrolysis
- Methanol steam reforming
- Ammonia cracker
- Hydrogen evaporation

Demand:
- Industry hydrogen
- Land transport hydrogen
- Fischer-Tropsch
- Methanolisation
- Haber-Bosch
- Hydrogen fuel cell CHP
- Sabatier
- Hydrogen export
- Hydrogen liquefication

Grids & Storage:
- New pipelines
- Retrofitted pipelines
- Storage in steel tanks

Liquid Hydrocarbons

Supply:
- Import
- Fossil oil refining
- Fischer-Tropsch

Storage:
- Hydrocarbon storage

Demand:
- Naphtha for industry
- Oil for services
- Kerosene for aviation
- Fuel oil for shipping
- Diesel/gasoline for land transport
- Diesel for agriculture
- Oil for residential

Methanol

Supply:
- Import
- Methanolisation

Storage:
- Hydrocarbon storage

Demand:
- Fuel methanol for shipping
- Industry methanol
- Methanol steam reforming (w/wo CC)
- Methanol export

Methane

Supply:
- Import
- Fossil gas
- Biogas upgrading (w CC)
- Sabatier

Storage:
- Hydrocarbon storage

Demand:
- Industry gas (w/wo CC)
- Services gas
- Residential gas
- Gas boiler
- Gas CHP
- Gas turbine (OCGT, CCGT)

Ammonia

Supply:
- Import
- Haber-Bosch

Storage:
- Ammonia tank

Demand:
- Industry ammonia
- Ammonia cracker
- Fuel ammonia for shipping
- Ammonia export

Heat

Supply:
- Air-sourced heat pump
- Industrial hat pump
- Ground-sourced heat pump (only rural)
- Resistive heater
- Gas boiler
- Oil boiler
- Solar thermal
- Water tank discharger
- Biomass CHP (w/wo CC, only DH)
- Gas CHP (w/wo CC, only DH)

Demand:
- Industry heat
- Residential heat
- Services heat
- Agriculture heat
- Direct air capture
- Water tank charger

Storage:
- Hot water tank

CO_2 atmosphere

Supply:
- Kerosene for aviation
- Diesel for agriculture
- Fuel methanol for shipping
- Oil for services
- Naphtha for industry
- Coal for industry
- Diesel/gasoline for land transport
- Fuel oil for shipping
- Gas boiler
- Gas CHP (w/wo CC)
- Gas turbine (OCGT, CCGT)
- Oil boiler
- Process emissions (w/wo CC)
- Fossil oil refining
- Coal, Lignite, Oil, Biomass powerplant
- Industry gas (w/wo CC)
- Services gas
- Residential gas

Demand:
- Solid biomass for industry (w CC)
- Biomass CHP (w CC)
- Direct air capture

CO_2 commodity

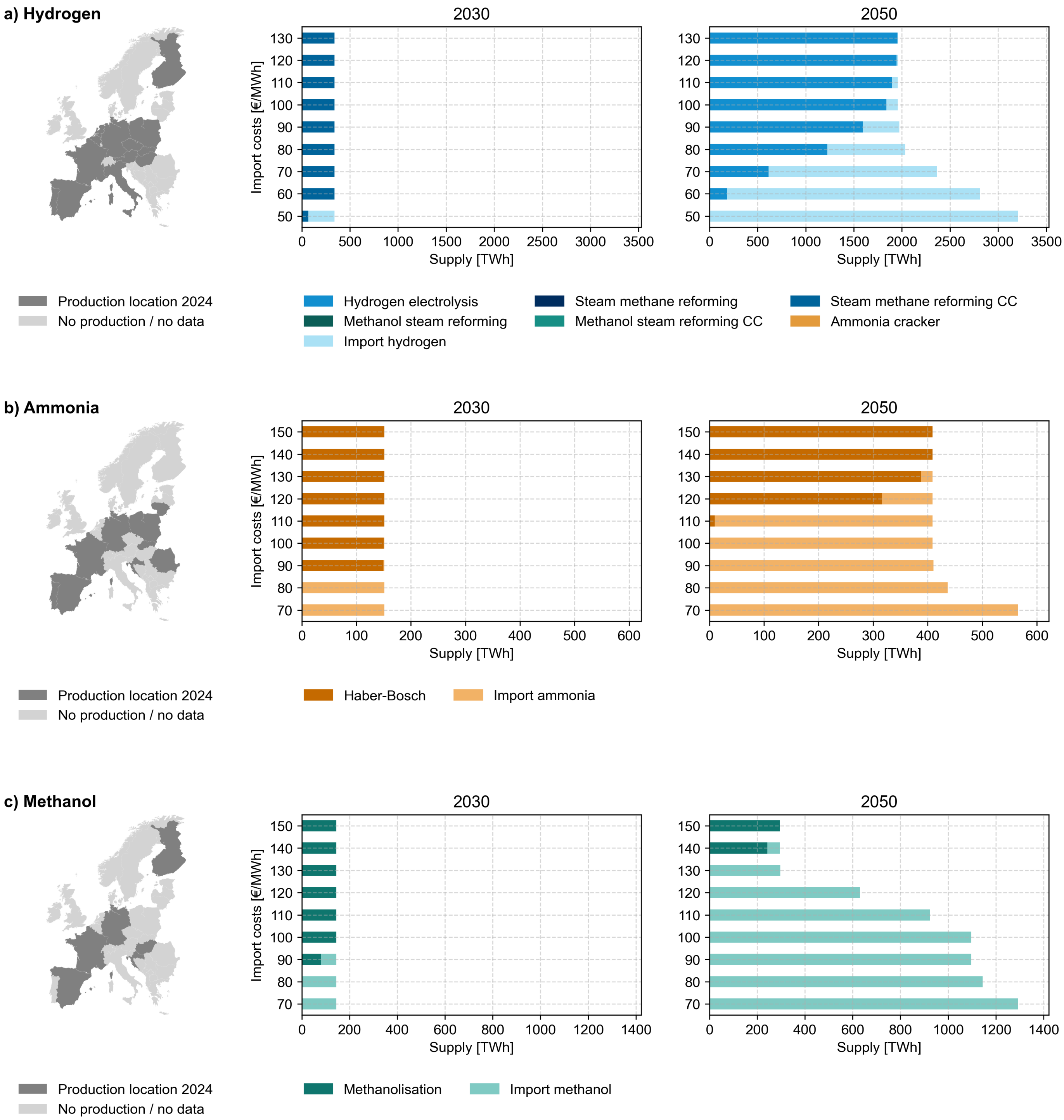
Supply:
- Direct air capture
- Biogas upgrading (w CC)
- Gas CHP (w CC)
- Process emissions (w CC)
- Solid biomass for industry (w CC)
- Industry gas (w CC)

Demand:
- Fischer-Tropsch
- Methanolisation
- Sequestration
- Sabatier

Storage:
- Intermediate storage in steel tank
- Long-term geological sequestration

Supplementary Figure 2: Overview of the energy system modelling options by carrier in PyPSA-Earth (1.5 °C path) for African countries in 2030 and 2050. The structure is based on the scenarios analysed in this research and builds on refs. [1,2], with modifications by the author. AC = alternating current; DC = direct current; OCGT = open cycle gas turbine; CCGT = combined cycle gas turbine; CHP = combined heat and power; CC = carbon capture; DH = district heating.

Supplementary Results: European energy system and varying import costs – GreenDeal scenario, Supply structure, 7% WACC

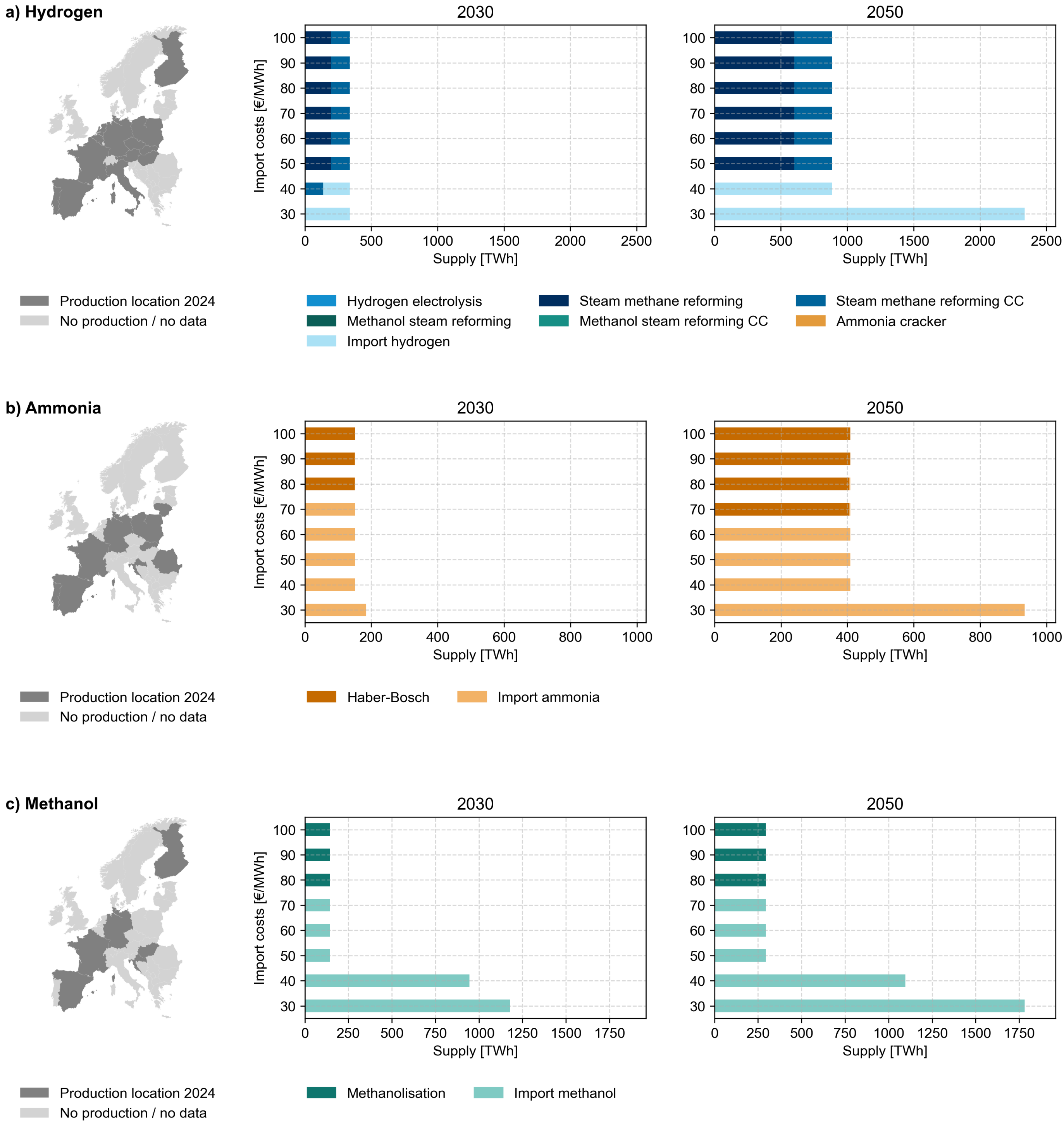


Supplementary Figure 3: Impact of import costs on domestic production of hydrogen, ammonia, and methanol in Europe. Domestic production by technology and imports are shown for varying import costs in 2030 and 2050 under the GreenDeal scenario, assuming a weighted average cost of capital (WACC) of 7%. Import costs range from 50-150 €/MWh, depending on the energy carrier, with a resolution of 10 €/MWh. Maps show the current production locations in Europe in 2024 [3].

Supplementary Results: European energy system and varying import costs – GreenDeal scenario, Demand structure, 7% WACC

Supplementary Figure 4: Impact of import costs on domestic demand of hydrogen, ammonia, and methanol in Europe. Domestic demand by technology are shown for varying import costs in 2030 and 2050 under the GreenDeal scenario, assuming a weighted average cost of capital (WACC) of 7%. Import costs range from 50-150 €/MWh, depending on the energy carrier, with a resolution of 10 €/MWh. Maps show the current demand locations in Europe in 2024[3,4].

Supplementary Results: European energy system and varying import costs – Business-as-Usual scenario, Supply structure, 7% WACC

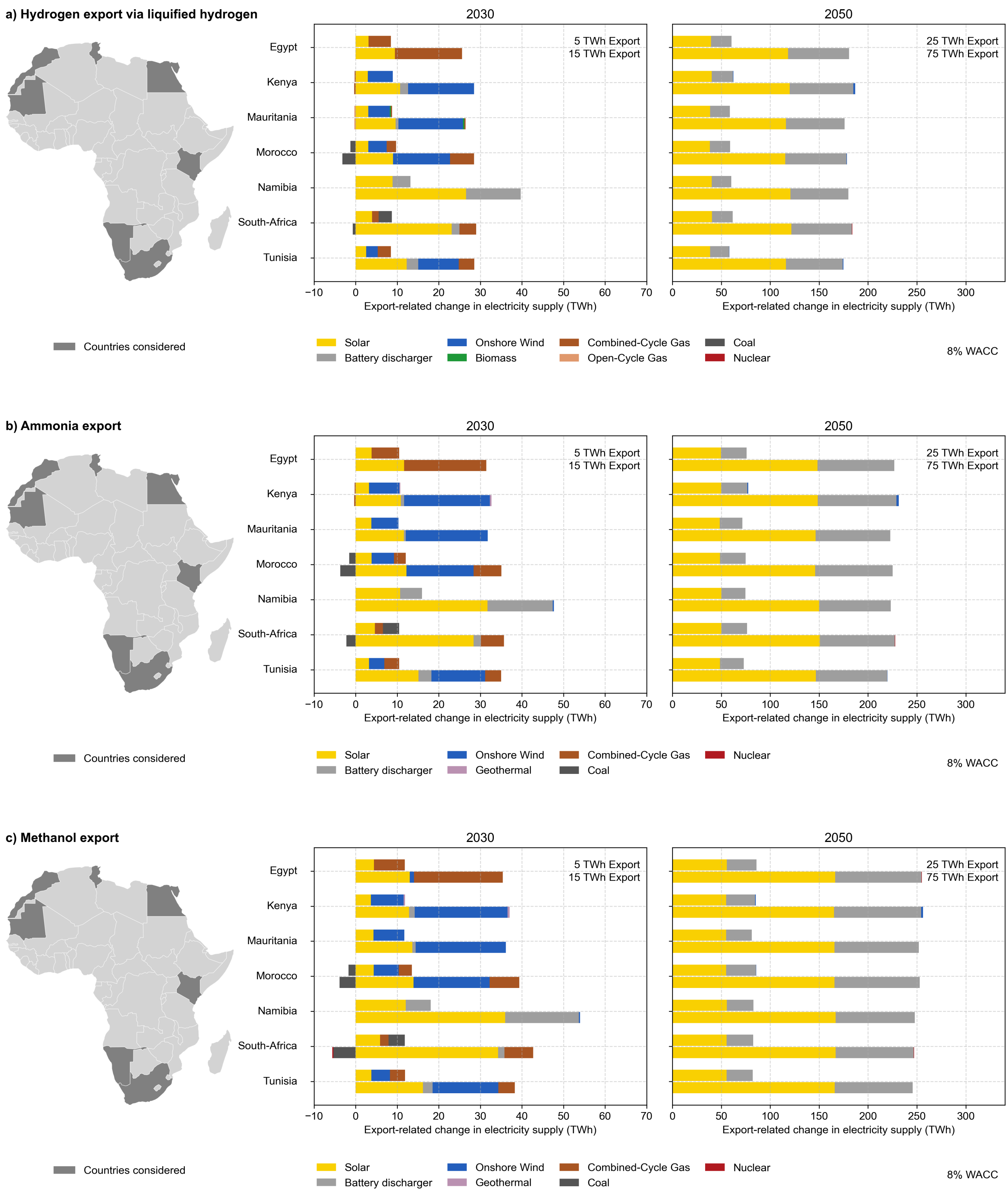


Supplementary Figure 5: Impact of import costs on domestic production of hydrogen, ammonia, and methanol in Europe. Domestic production by technology and imports are shown for varying import costs in 2030 and 2050 under the Business-as-Usual scenario, assuming a weighted average cost of capital (WACC) of 7%. Import costs range from 30-100 €/MWh, depending on the energy carrier, with a resolution of 10 €/MWh. Maps show the current production locations in Europe in 2024[3].

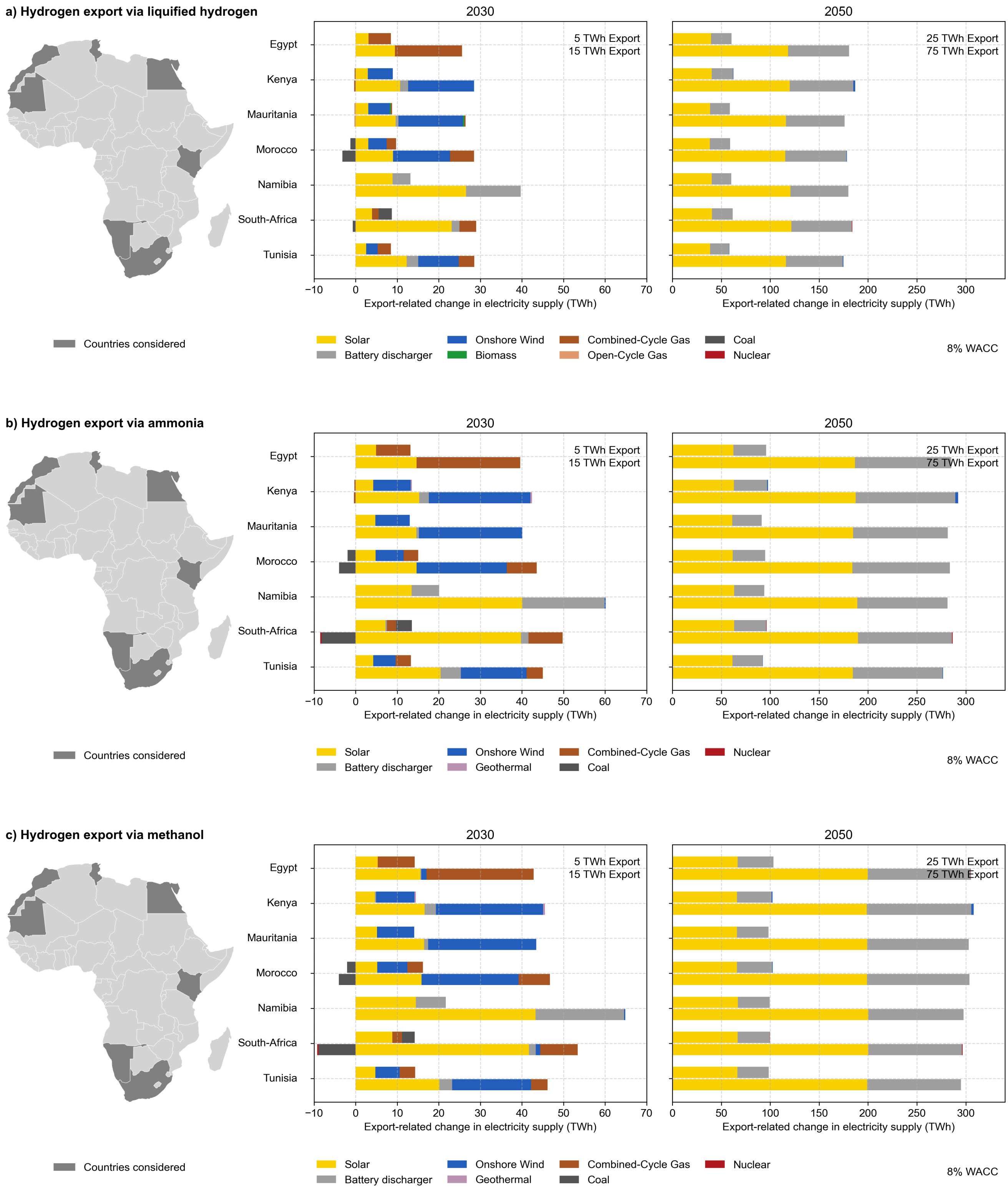
Supplementary Results: European energy system and varying import costs – Business-as-Usual scenario, Demand structure, 7% WACC

Supplementary Figure 6: Impact of import costs on domestic production of hydrogen, ammonia, and methanol in Europe. Domestic production by technology and imports are shown for varying imports costs in 2030 and 2050 under the GreenDeal scenario, assuming a weighted average cost of capital (WACC) of 7%. Vertical lines indicate total supply in the GreenDeal and Business-as-Usual (BAU) scenarios. Maps show the current production locations in Europe in 2024[3,4].

Supplementary Results: African energy systems and varying export volumes – Export-related change in electricity supply, 8% WACC

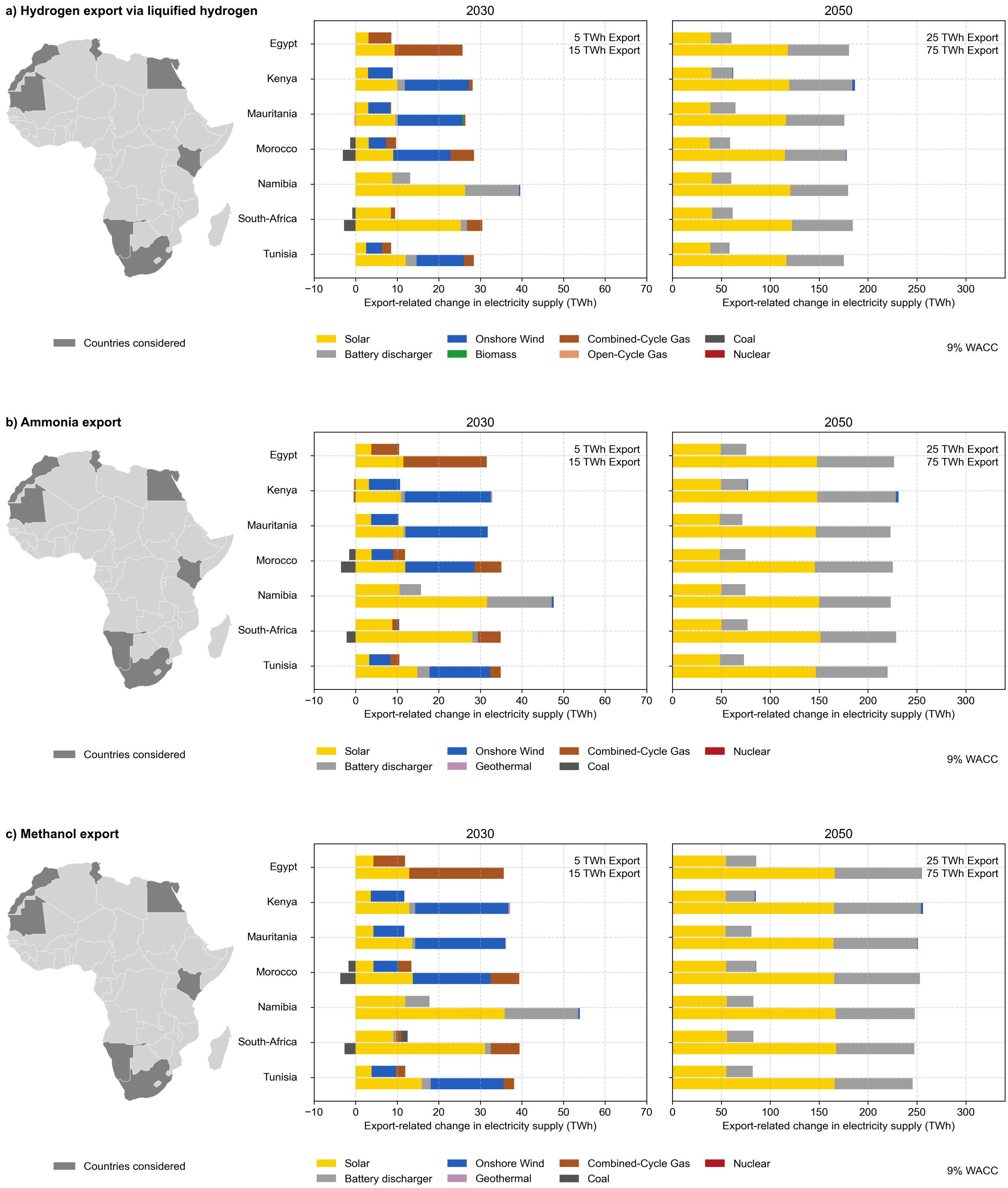


Supplementary Figure 7: Impact of hydrogen, ammonia, and methanol export volumes on domestic electricity supply in selected African countries. Changes in electricity supply by technology are shown for different export volumes in 2030 and 2050, assuming a weighted average cost of capital (WACC) of 8%. Results are reported relative to a non-export scenario. Maps indicate the African countries considered in the analysis.

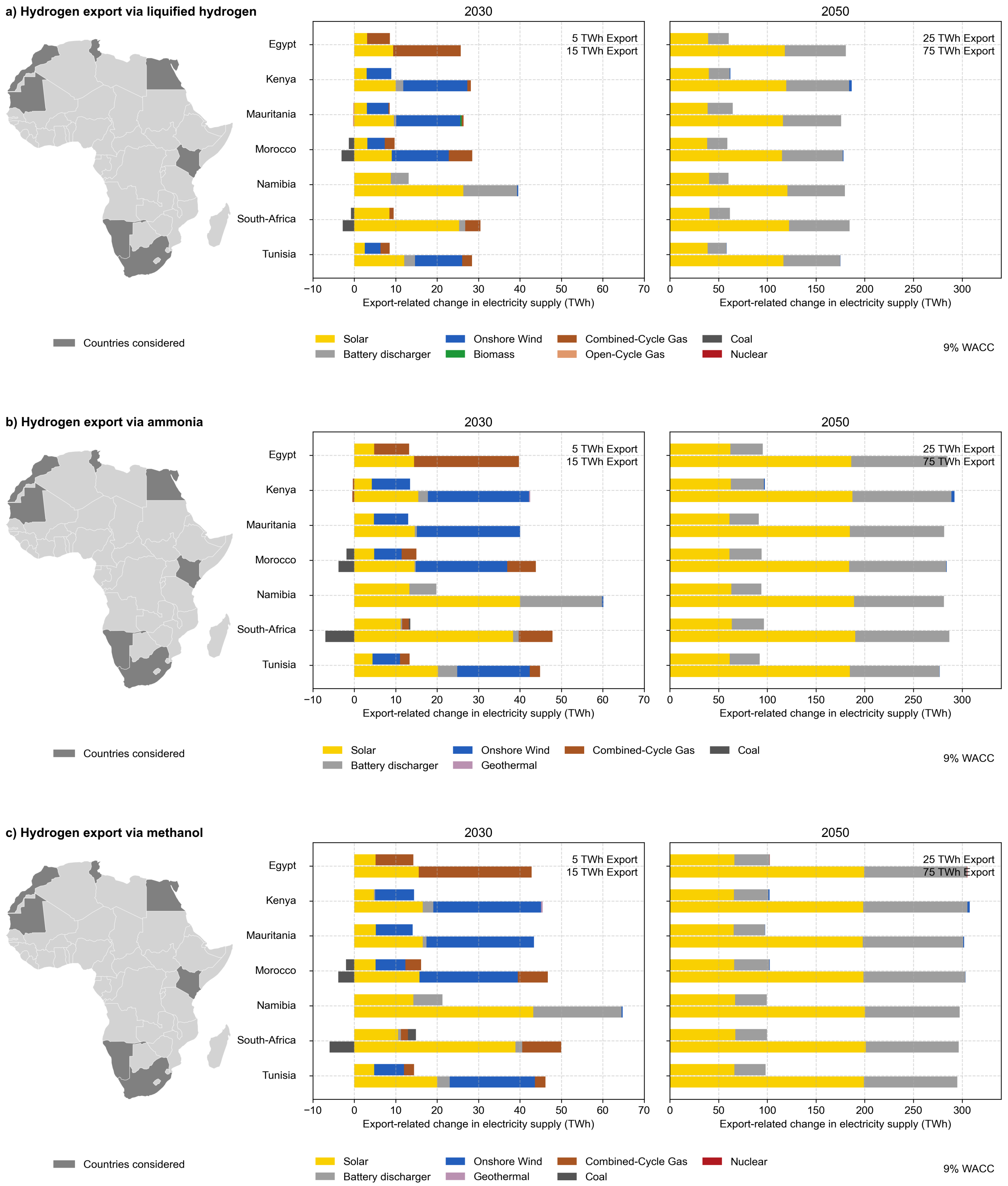


Supplementary Figure 8: Impact of hydrogen export volumes and shipping pathways on domestic electricity supply in selected African countries. Liquefied hydrogen, ammonia and methanol pathways include hydrogen reconversion. Changes in electricity supply by technology are shown for different export volumes in 2030 and 2050, assuming a weighted average cost of capital (WACC) of 8%. Results are reported relative to a non-export scenario. Maps indicate the African countries considered in the analysis.

Supplementary Results: African energy systems and varying export volumes – Export-related change in electricity supply, 9% WACC

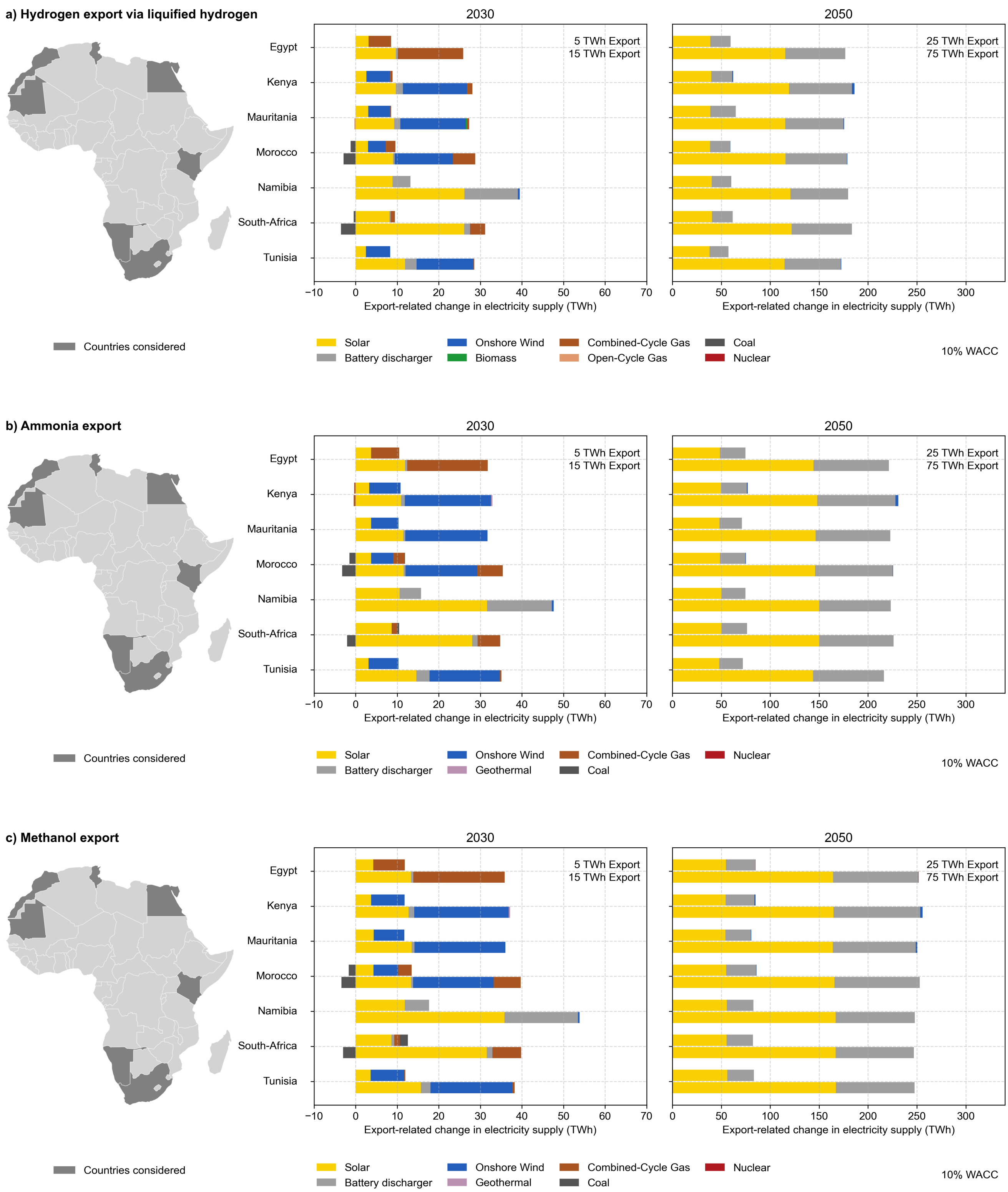


Supplementary Figure 9: Impact of hydrogen, ammonia, and methanol export volumes on domestic electricity supply in selected African countries. Changes in electricity supply by technology are shown for different export volumes in 2030 and 2050, assuming a weighted average cost of capital (WACC) of 9%. Results are reported relative to a non-export scenario. Maps indicate the African countries considered in the analysis.

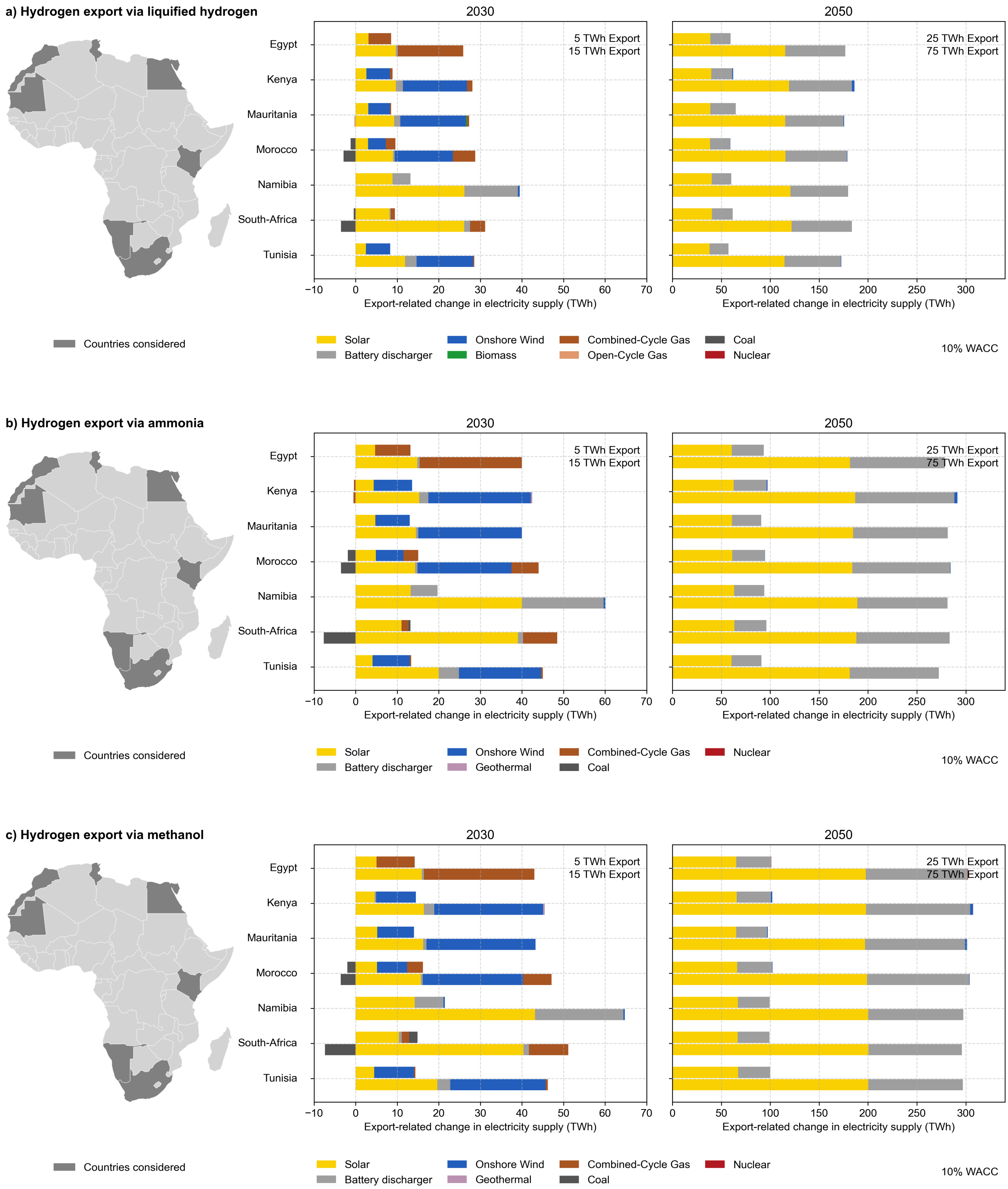


Supplementary Figure 10: Impact of hydrogen export volumes and shipping pathways on domestic electricity supply in selected African countries. Liquefied hydrogen, ammonia and methanol pathways include hydrogen reconversion. Changes in electricity supply by technology are shown for different export volumes in 2030 and 2050, assuming a weighted average cost of capital (WACC) of 9%. Results are reported relative to a non-export scenario. Maps indicate the African countries considered in the analysis.

Supplementary Results: African energy systems and varying export volumes – Export-related change in electricity supply, 10% WACC

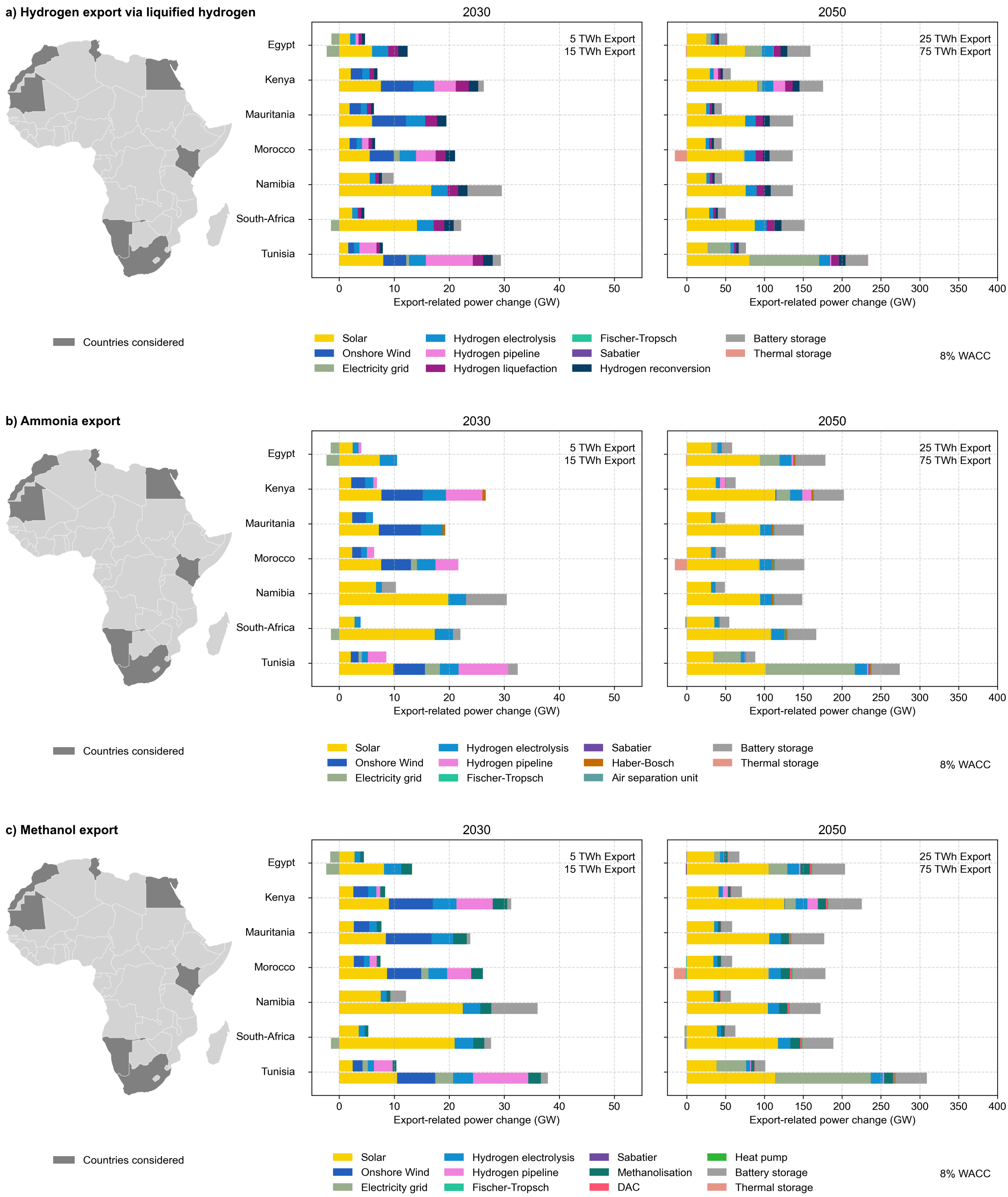


Supplementary Figure 11: Impact of hydrogen, ammonia, and methanol export volumes on domestic electricity supply in selected African countries. Changes in electricity supply by technology are shown for different export volumes in 2030 and 2050, assuming a weighted average cost of capital (WACC) of 10%. Results are reported relative to a non-export scenario. Maps indicate the African countries considered in the analysis.

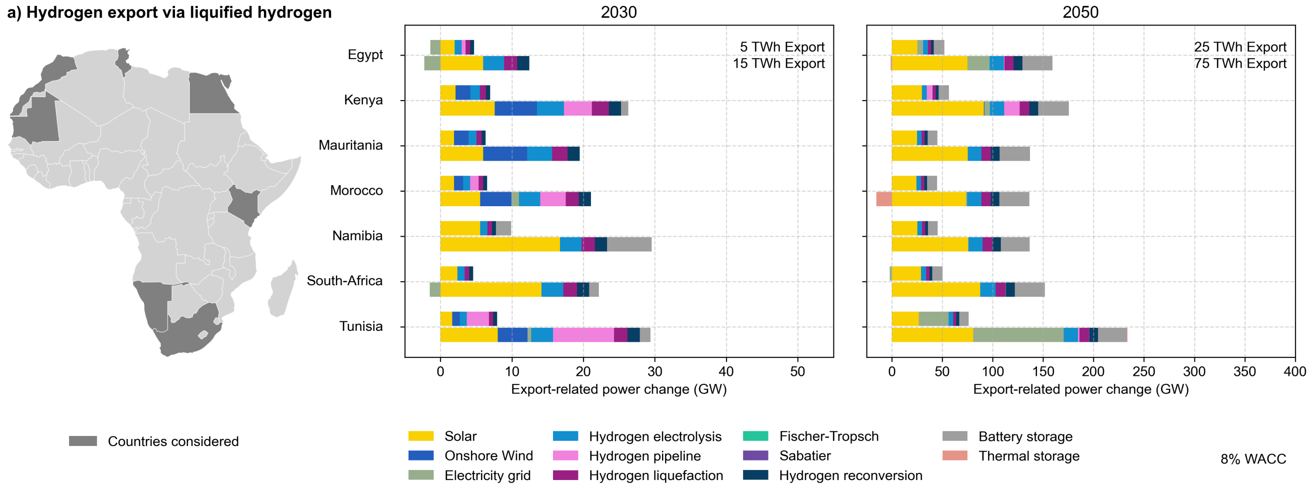


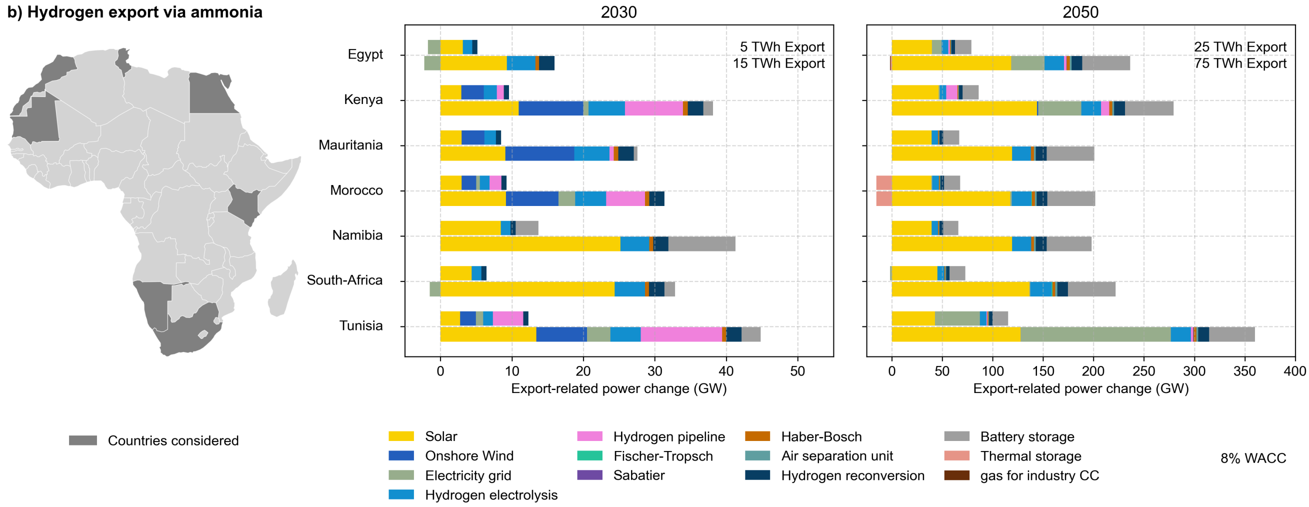
Supplementary Figure 12: Impact of hydrogen export volumes and shipping pathways on domestic electricity supply in selected African countries. Liquefied hydrogen, ammonia and methanol pathways include hydrogen reconversion. Changes in electricity supply by technology are shown for different export volumes in 2030 and 2050, assuming a weighted average cost of capital (WACC) of 10%. Results are reported relative to a non-export scenario. Maps indicate the African countries considered in the analysis.

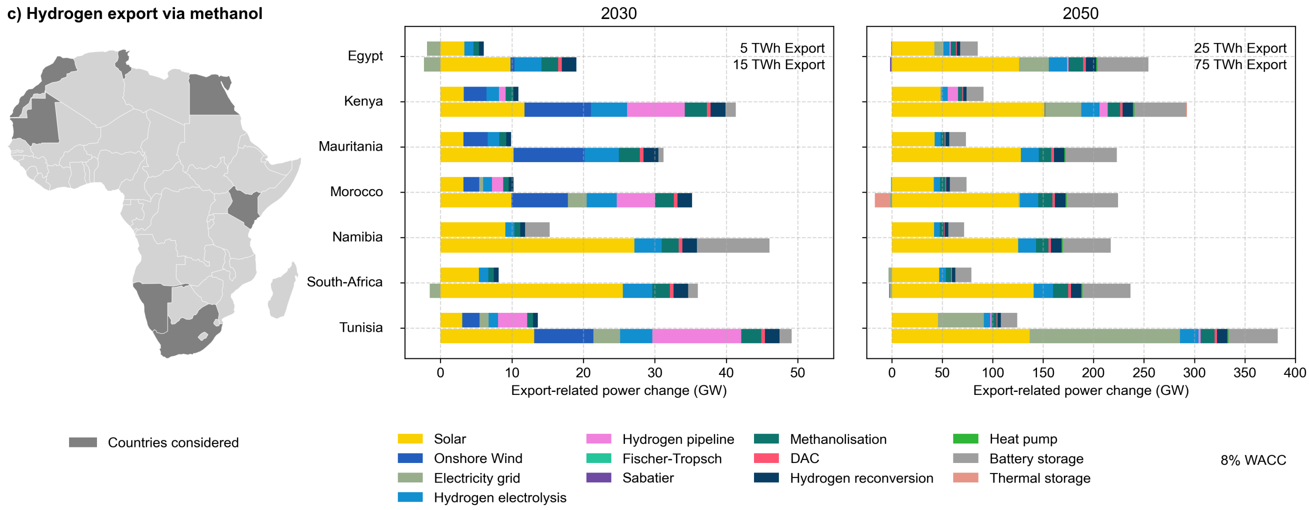
Supplementary Results: African energy systems and varying export volumes – Export-related power change, 8% WACC



Supplementary Figure 13: Impact of hydrogen, ammonia, and methanol export volumes on domestic power capacity in selected African countries. Changes in power capacity by technology are shown for different export volumes in 2030 and 2050, assuming a weighted average cost of capital (WACC) of 8%. Results are reported relative to a non-export scenario. Maps indicate the African countries considered in the analysis.

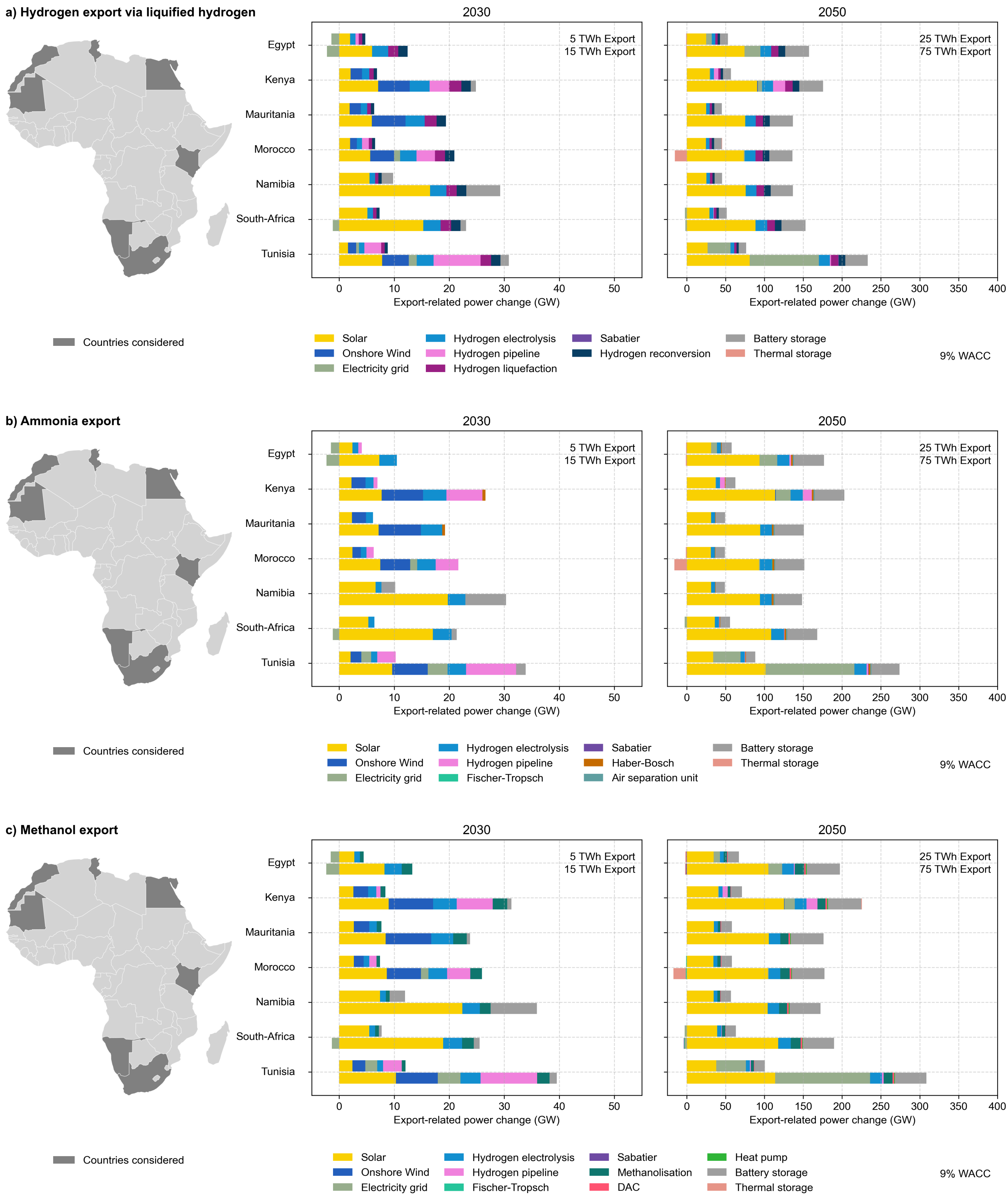




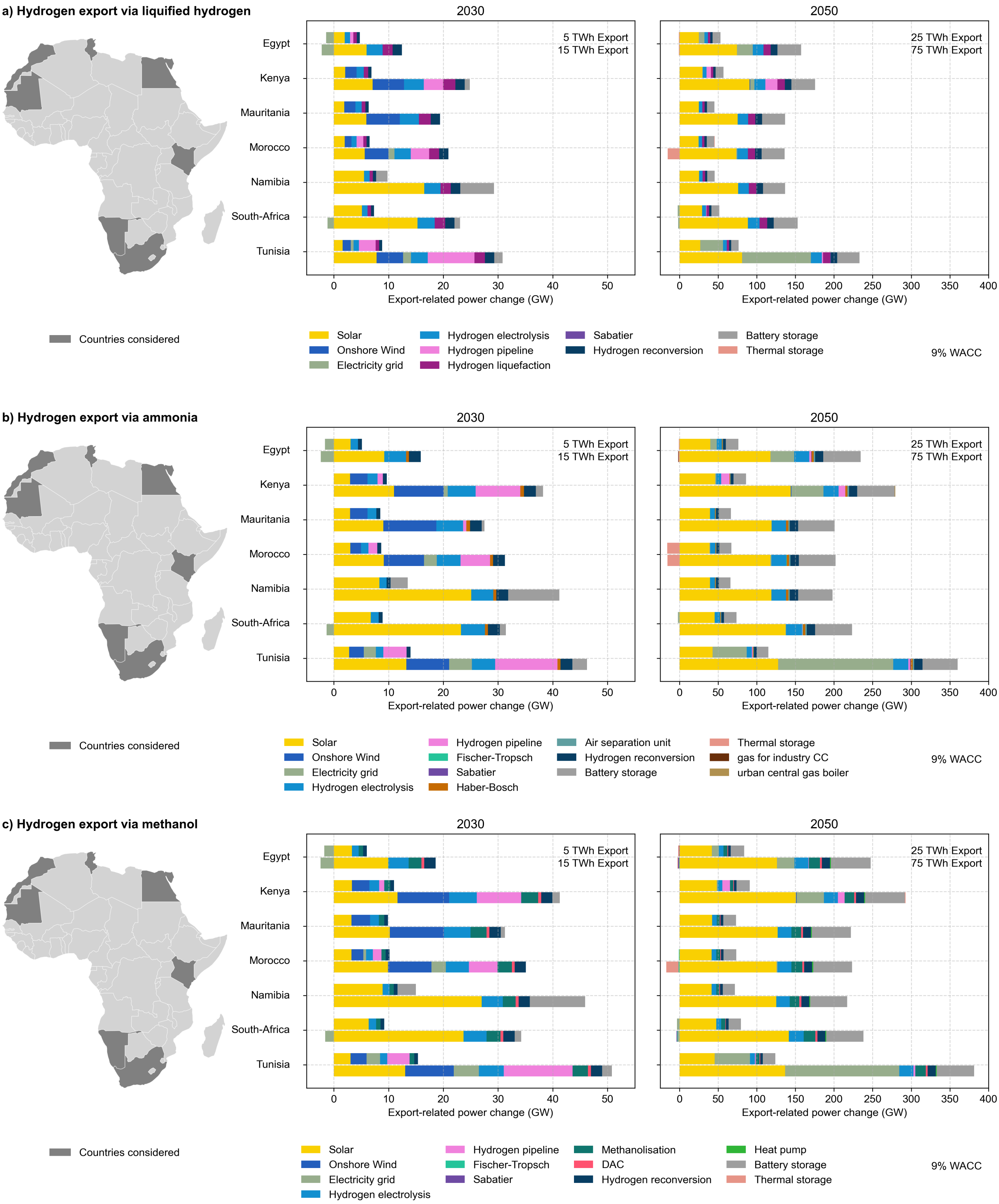


Supplementary Figure 14: Impact of hydrogen export volumes and shipping pathways on domestic power capacity in selected African countries. Liquefied hydrogen, ammonia and methanol pathways include hydrogen reconversion. Changes in power capacity by technology are shown for different export volumes in 2030 and 2050, assuming a weighted average cost of capital (WACC) of 8%. Results are reported relative to a non-export scenario. Maps indicate the African countries considered in the analysis.

Supplementary Results: African energy systems and varying export volumes – Export-related power change, 9% WACC

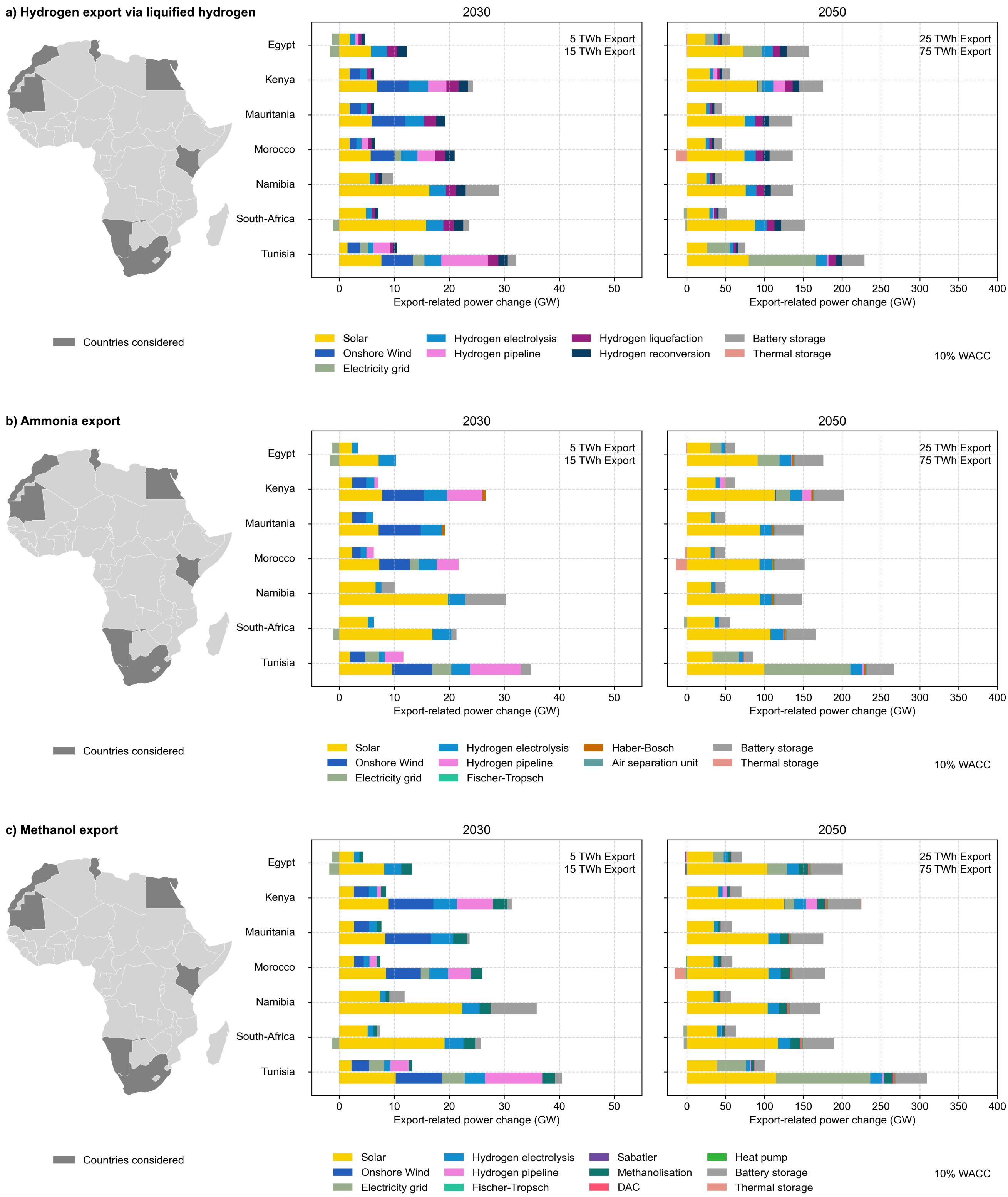


Supplementary Figure 15: Impact of hydrogen, ammonia, and methanol export volumes on domestic power capacity in selected African countries. Changes in power capacity by technology are shown for different export volumes in 2030 and 2050, assuming a weighted average cost of capital (WACC) of 9%. Results are reported relative to a non-export scenario. Maps indicate the African countries considered in the analysis.

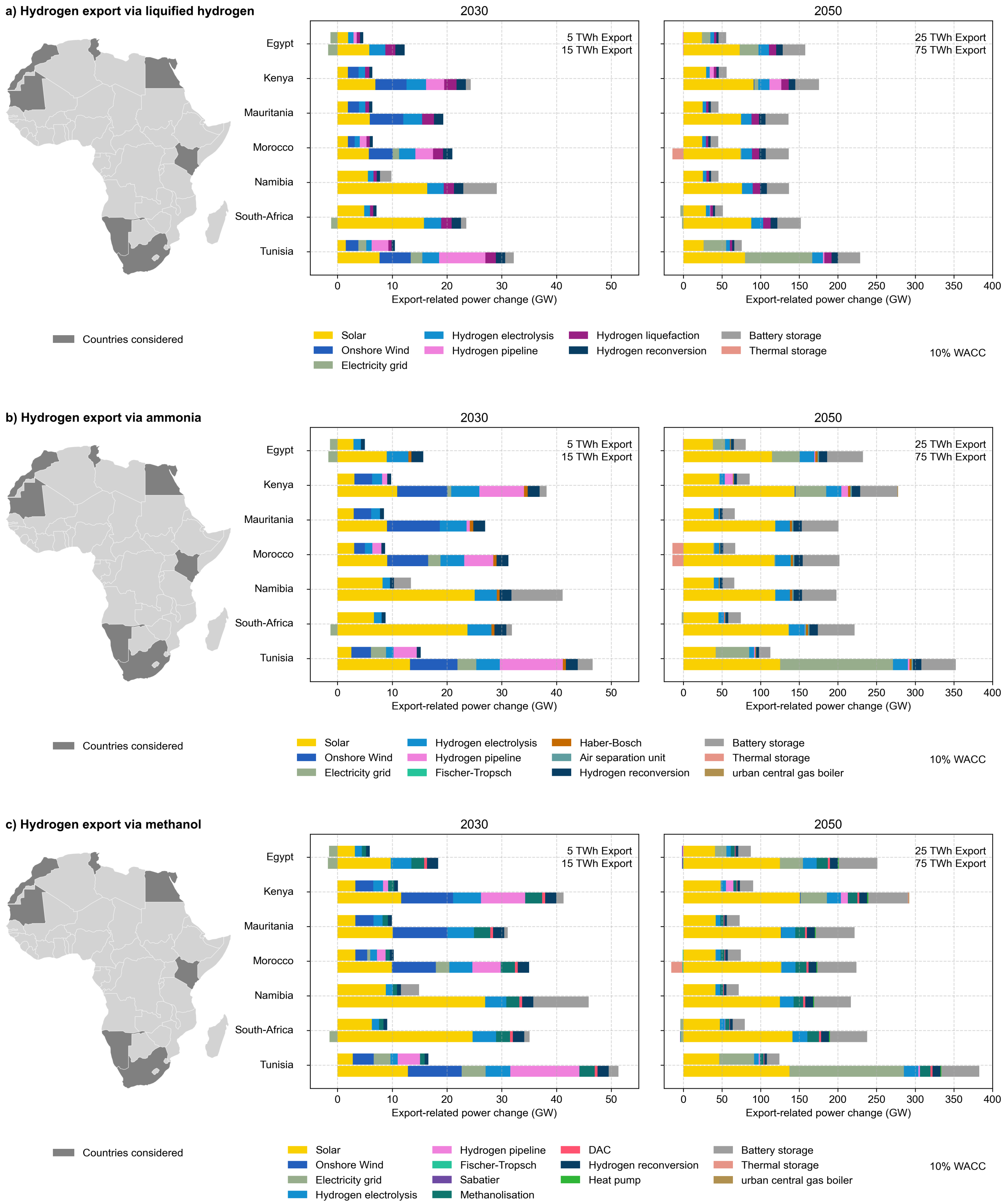


Supplementary Figure 16: Impact of hydrogen export volumes and shipping pathways on domestic power capacity in selected African countries. Liquefied hydrogen, ammonia and methanol pathways include hydrogen reconversion. Changes in power capacity by technology are shown for different export volumes in 2030 and 2050, assuming a weighted average cost of capital (WACC) of 9%. Results are reported relative to a non-export scenario. Maps indicate the African countries considered in the analysis.

Supplementary Results: African energy systems and varying export volumes – Export-related power change, 10% WACC

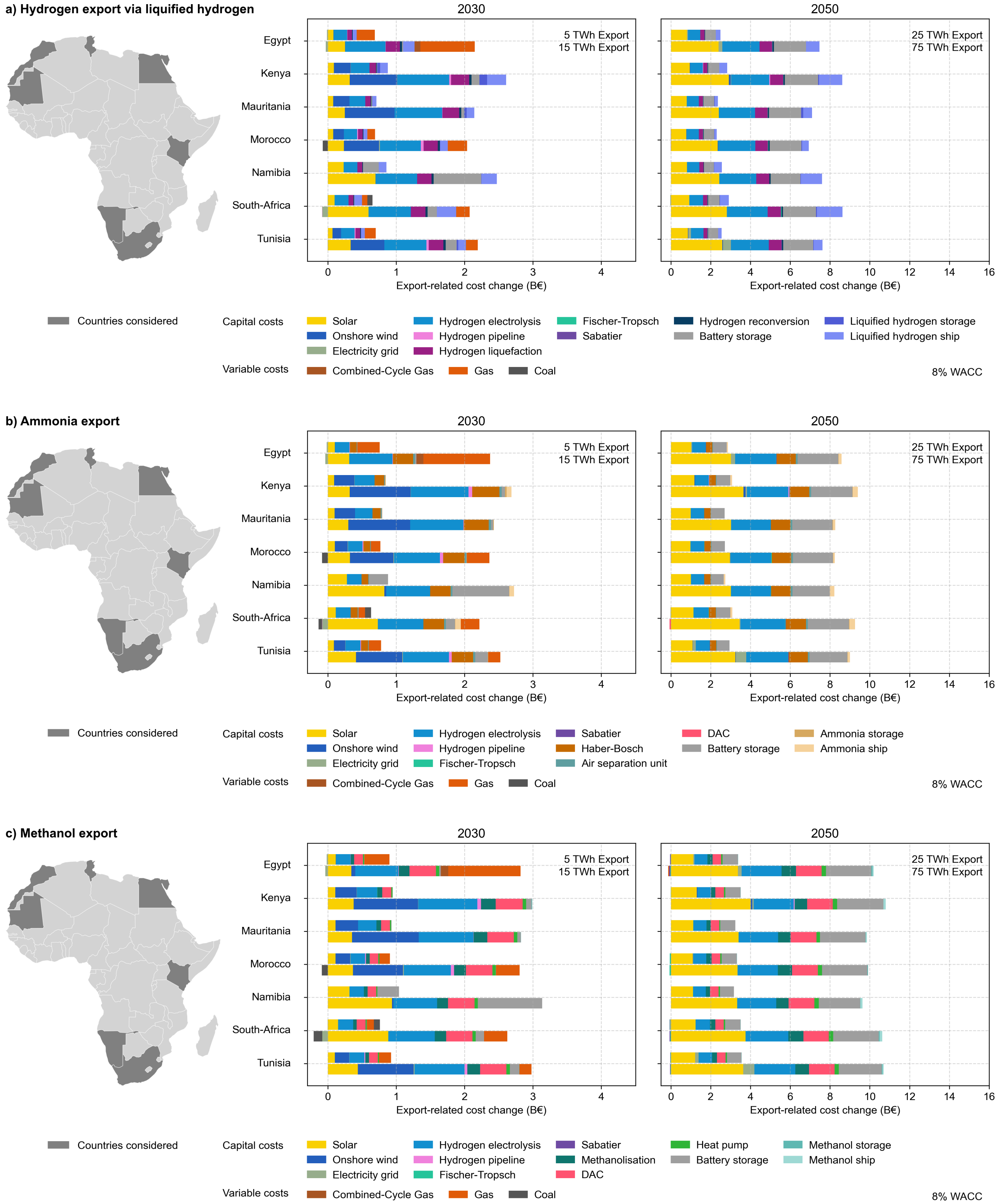


Supplementary Figure 17: Impact of hydrogen, ammonia, and methanol export volumes on domestic power capacity in selected African countries. Changes in power capacity by technology are shown for different export volumes in 2030 and 2050, assuming a weighted average cost of capital (WACC) of 10%. Results are reported relative to a non-export scenario. Maps indicate the African countries considered in the analysis.

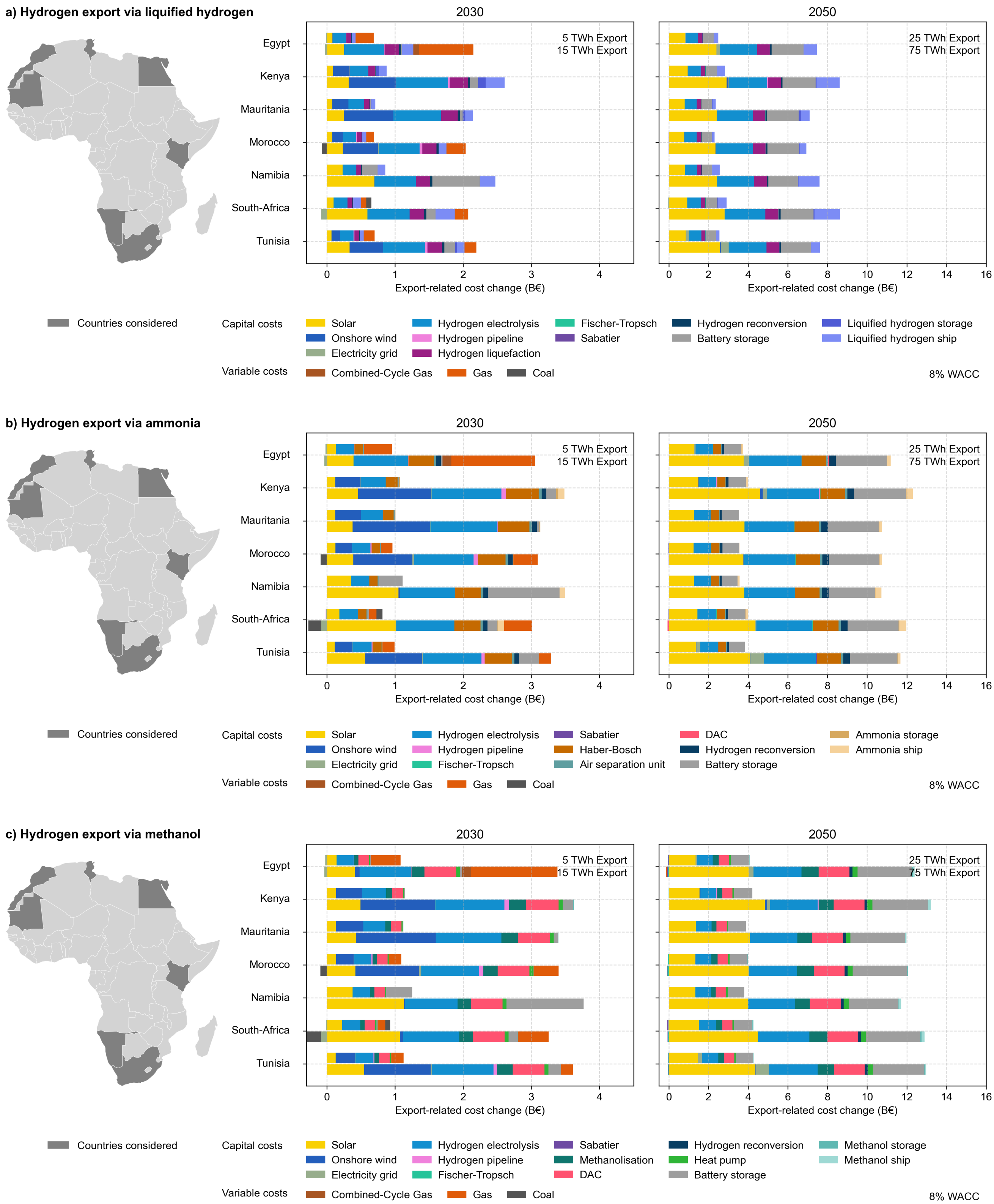


Supplementary Figure 18: Impact of hydrogen export volumes and shipping pathways on domestic power capacity in selected African countries. Liquefied hydrogen, ammonia and methanol pathways include hydrogen reconversion. Changes in power capacity by technology are shown for different export volumes in 2030 and 2050, assuming a weighted average cost of capital (WACC) of 10%. Results are reported relative to a non-export scenario. Maps indicate the African countries considered in the analysis.

Supplementary Results: African energy systems and varying export volumes – Export-related cost change, 8% WACC

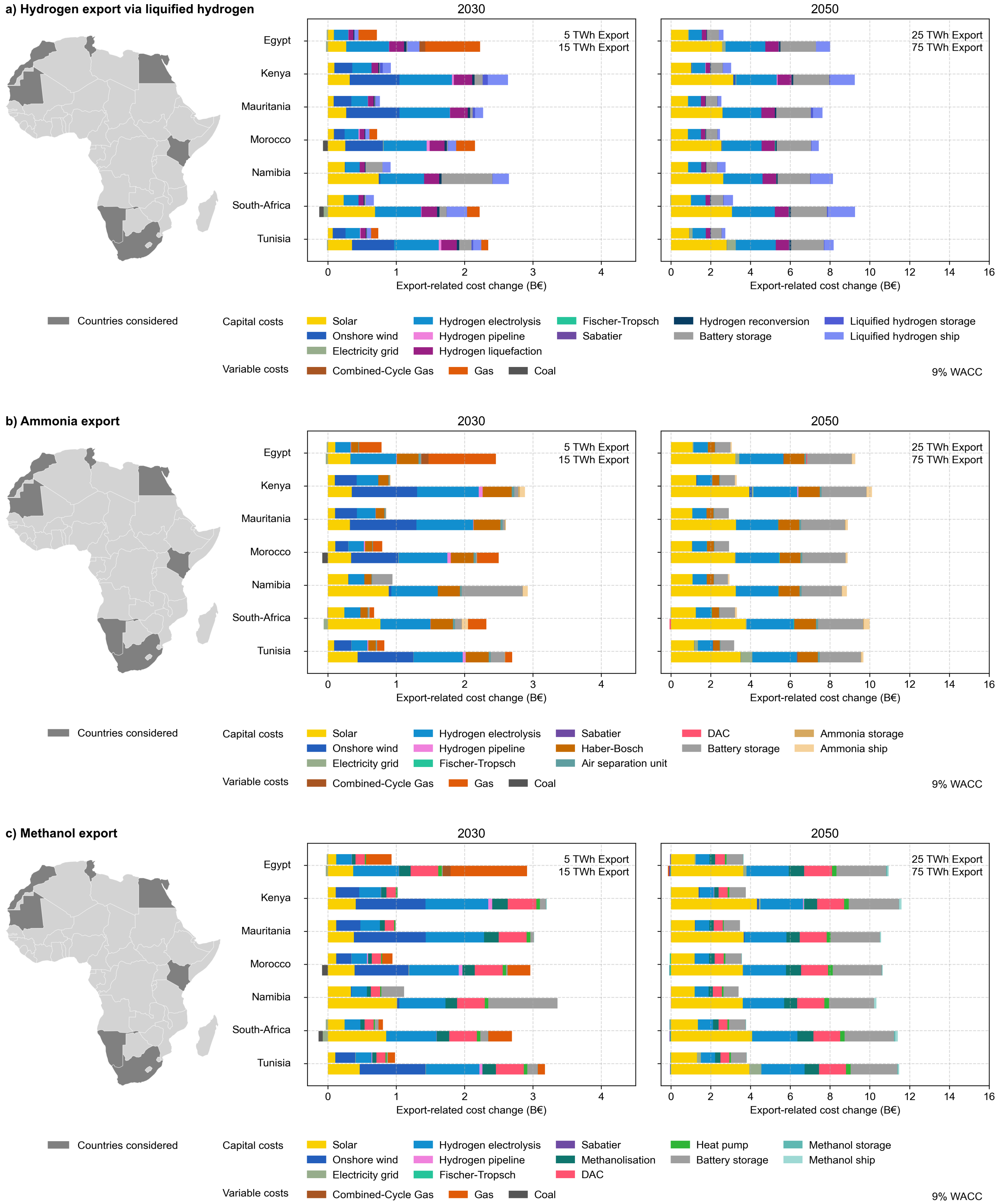


Supplementary Figure 19: Impact of hydrogen, ammonia, and methanol export volumes on additional costs in selected African countries. Changes in costs by technology are shown for different export volumes in 2030 and 2050, assuming a weighted average cost of capital (WACC) of 8%. Results are reported relative to a non-export scenario. Maps indicate the African countries considered in the analysis.

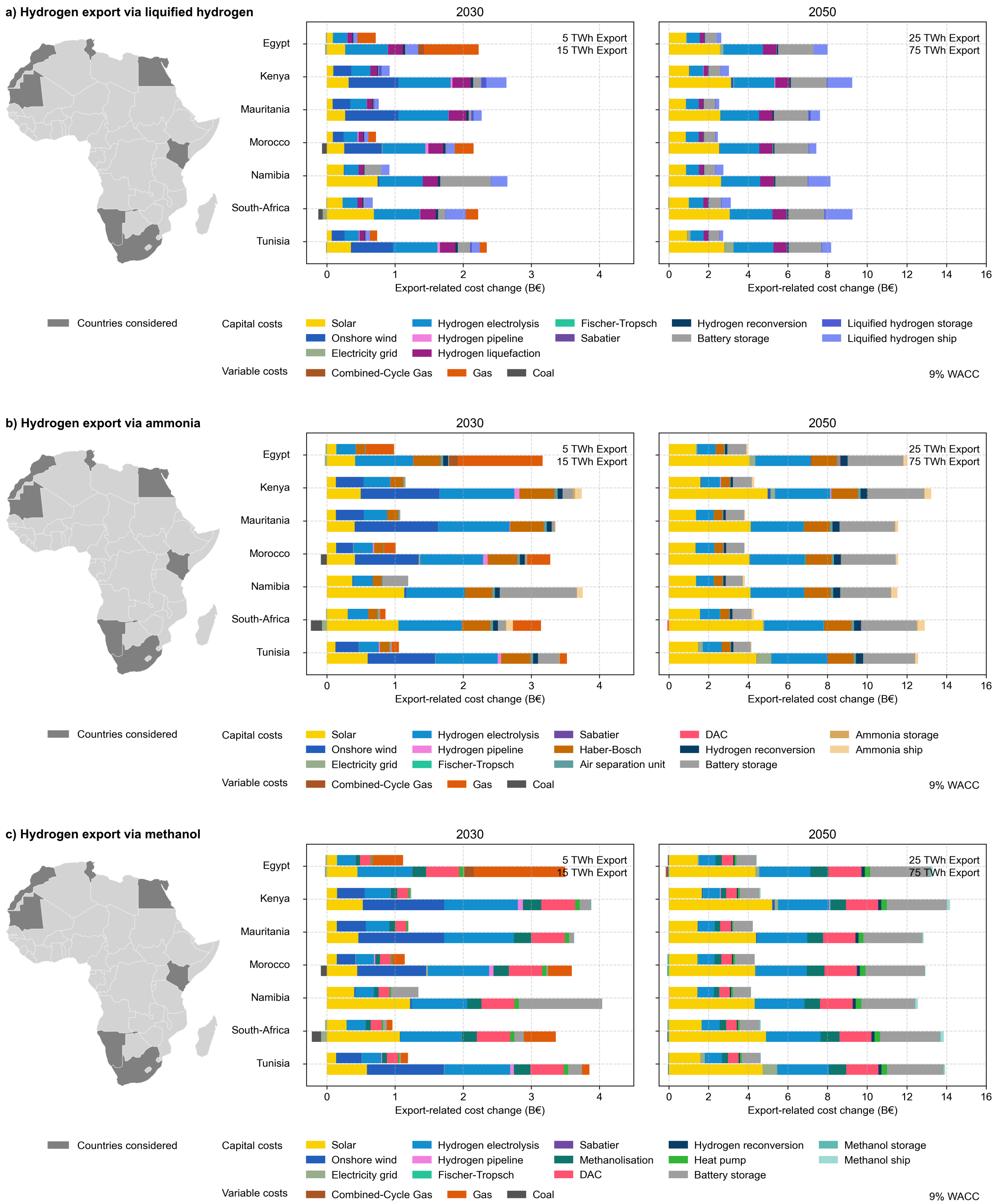


Supplementary Figure 20: Impact of hydrogen export volumes and shipping pathways on additional costs in selected African countries. Liquefied hydrogen, ammonia and methanol pathways include hydrogen reconversion. Changes in costs by technology are shown for different export volumes in 2030 and 2050, assuming a weighted average cost of capital (WACC) of 8%. Results are reported relative to a non-export scenario. Maps indicate the African countries considered in the analysis.

Supplementary Results: African energy systems and varying export volumes – Export-related cost change, 9% WACC

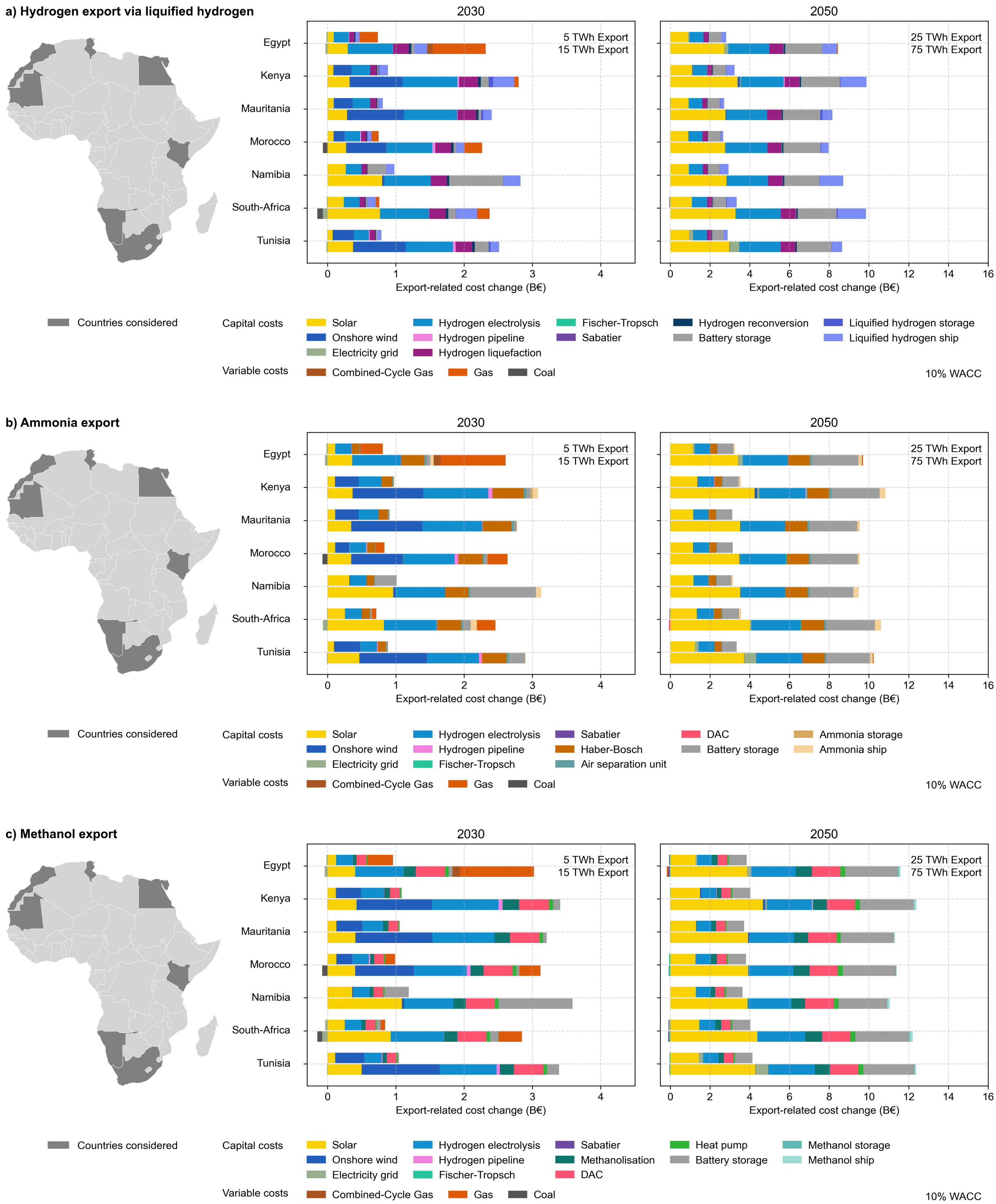


Supplementary Figure 21: Impact of hydrogen, ammonia, and methanol export volumes on additional costs in selected African countries. Changes in costs by technology are shown for different export volumes in 2030 and 2050, assuming a weighted average cost of capital (WACC) of 9%. Results are reported relative to a non-export scenario. Maps indicate the African countries considered in the analysis.

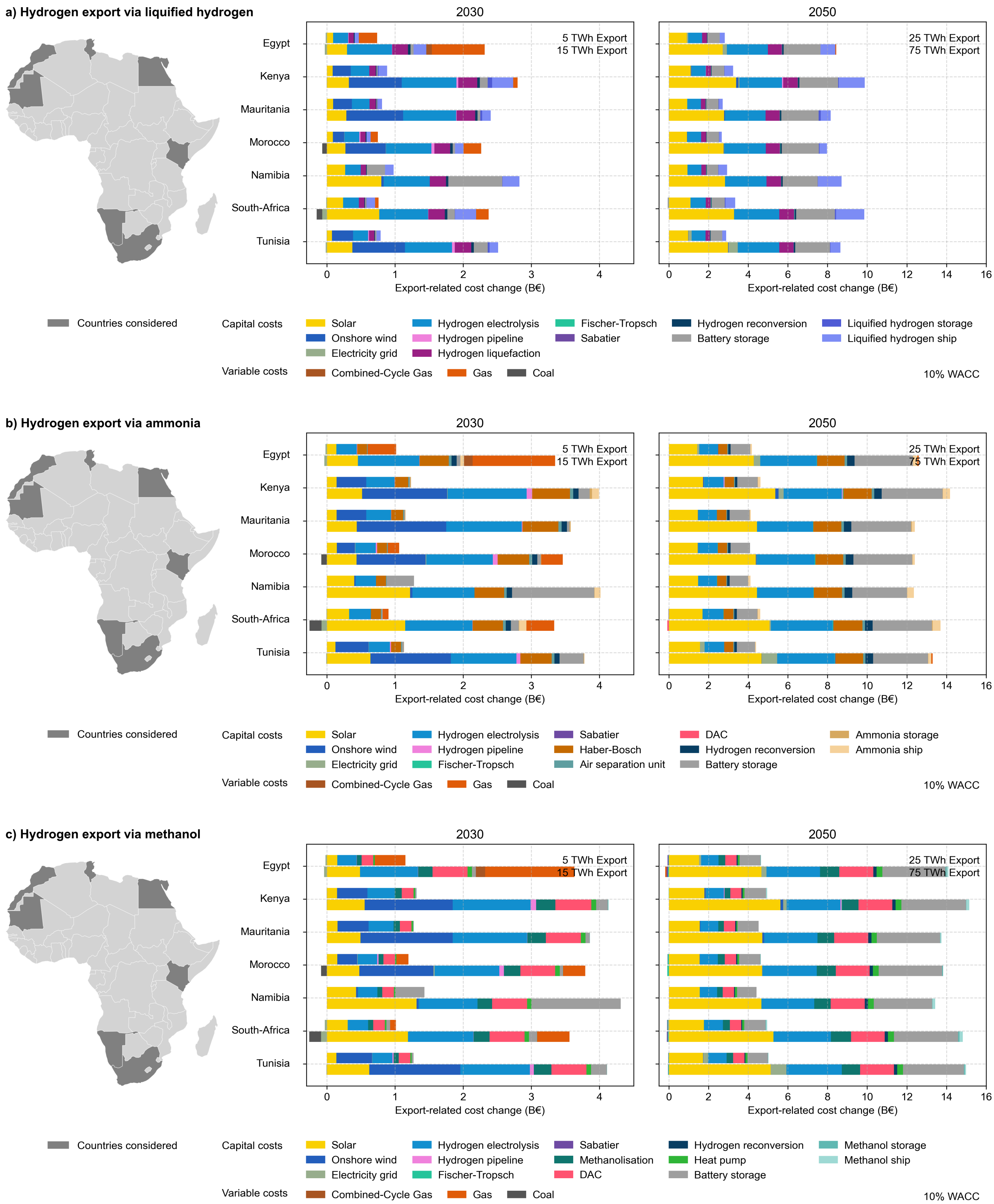


Supplementary Figure 22: Impact of hydrogen export volumes and shipping pathways on additional costs in selected African countries. Liquefied hydrogen, ammonia and methanol pathways include hydrogen reconversion. Changes in costs by technology are shown for different export volumes in 2030 and 2050, assuming a weighted average cost of capital (WACC) of 9%. Results are reported relative to a non-export scenario. Maps indicate the African countries considered in the analysis.

Supplementary Results: African energy systems and varying export volumes – Export-related cost change, 10% WACC

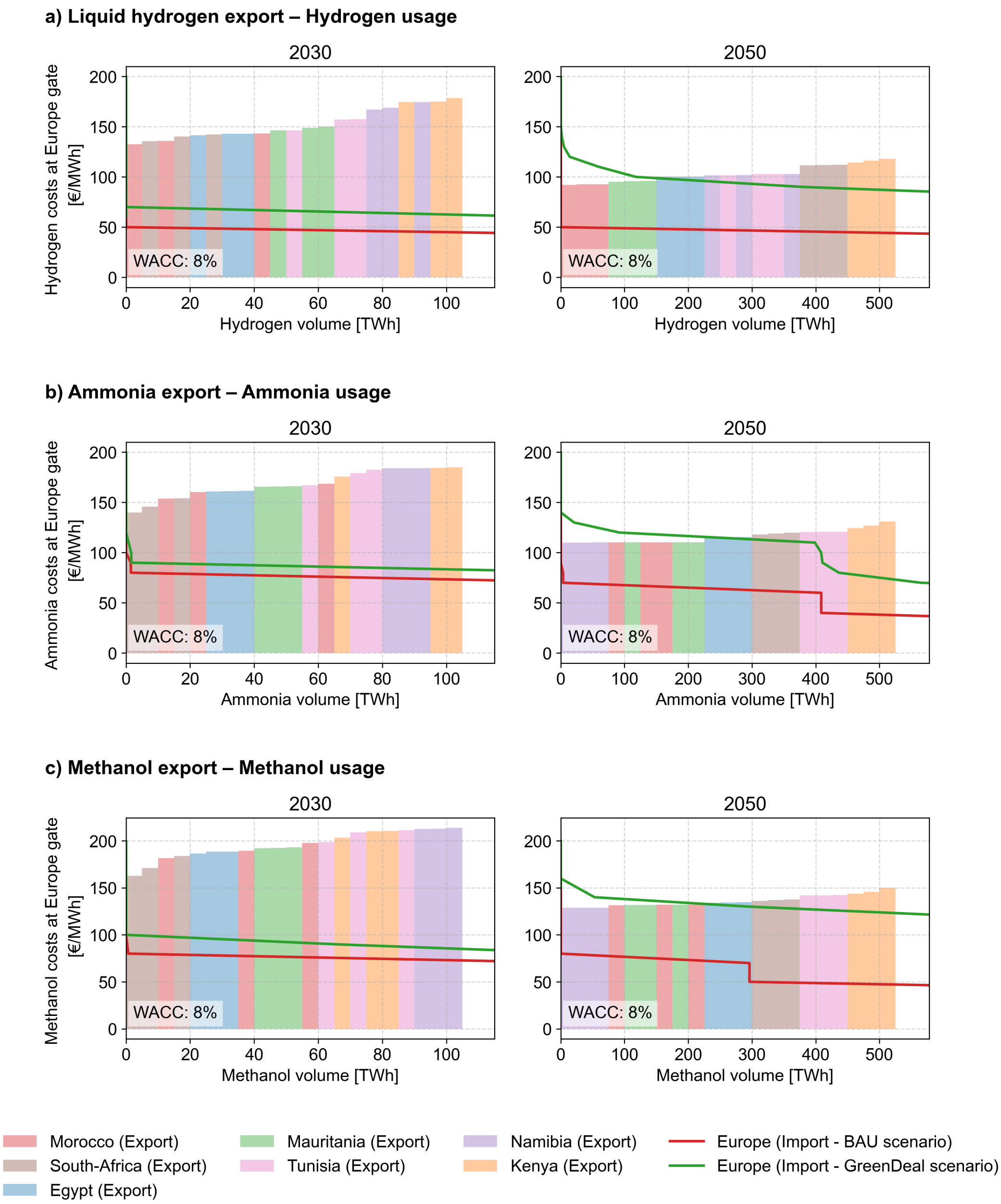


Supplementary Figure 23: Impact of hydrogen, ammonia, and methanol export volumes on additional costs in selected African countries. Changes in costs by technology are shown for different export volumes in 2030 and 2050, assuming a weighted average cost of capital (WACC) of 10%. Results are reported relative to a non-export scenario. Maps indicate the African countries considered in the analysis.

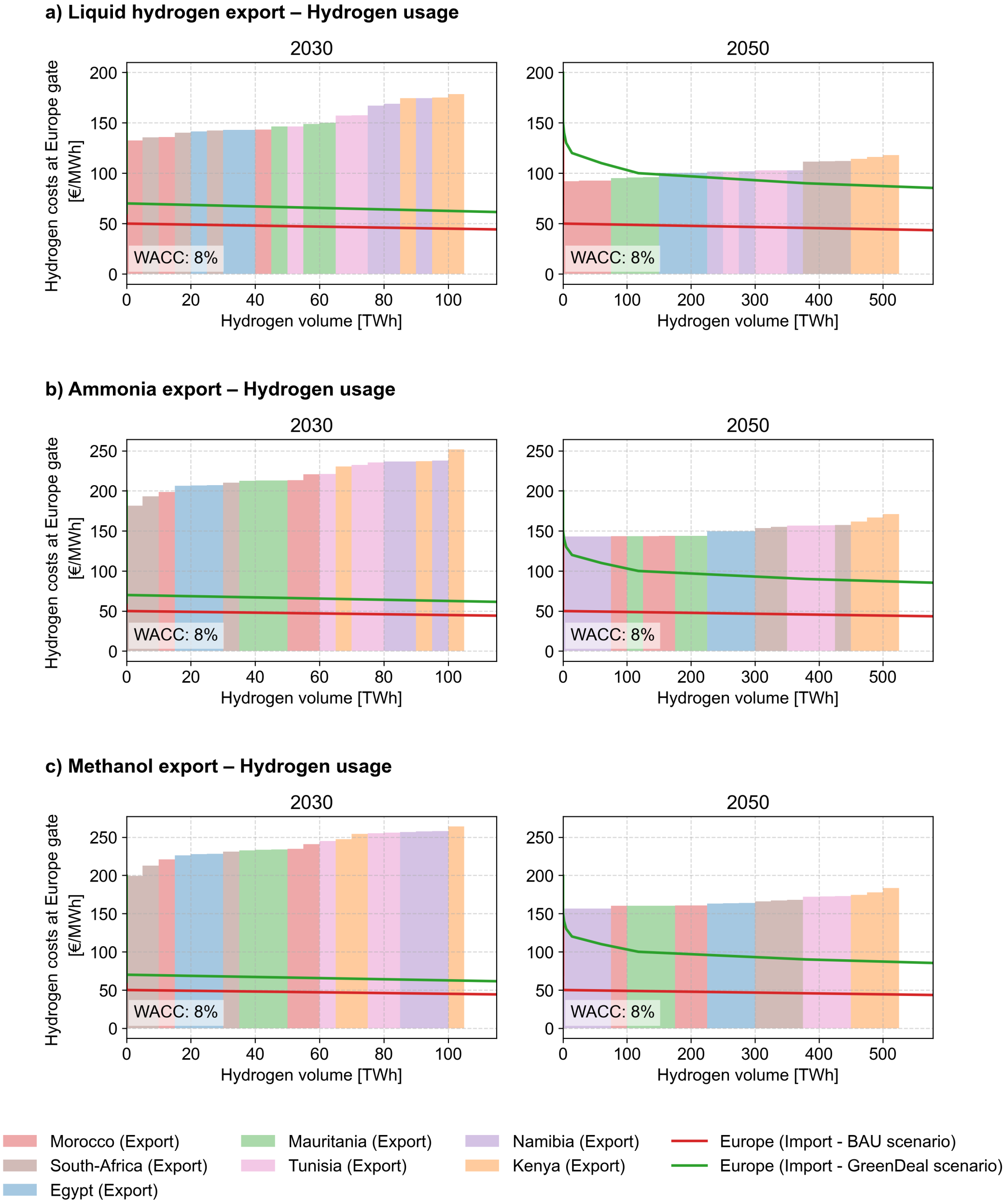


Supplementary Figure 24: Impact of hydrogen export volumes and shipping pathways on additional costs in selected African countries. Liquefied hydrogen, ammonia and methanol pathways include hydrogen reconversion. Changes in costs by technology are shown for different export volumes in 2030 and 2050, assuming a weighted average cost of capital (WACC) of 10%. Results are reported relative to a non-export scenario. Maps indicate the African countries considered in the analysis.

Supplementary Results: European-African energy exchange and the H2Global mechanism – 8% WACC

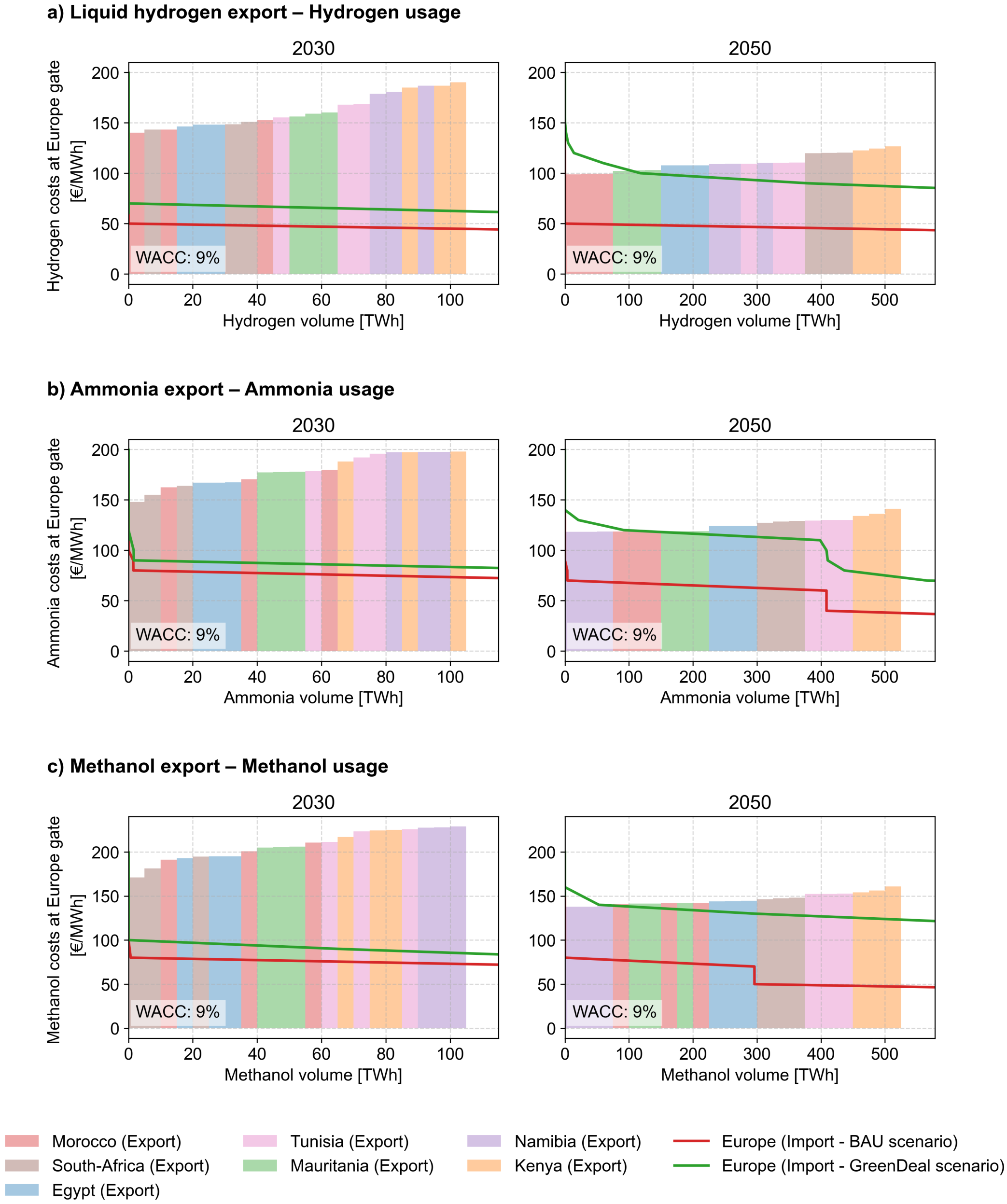


Supplementary Figure 25: European-African energy exchange of hydrogen, ammonia, and methanol. For Europe, the willingness to pay for green energy imports under the GreenDeal and Business-as-Usual (BAU) scenario is shown, assuming a weighted average cost of capital (WACC) of 7%. For African countries, the willingness to accept for green energy exports of 5, 10 and 15 TWh in 2030 and 25, 50 and 75 TWh in 2050 are shown, assuming a WACC of 8%. Comparing both results indicates funding, savings and the role of the H2Global mechanism.

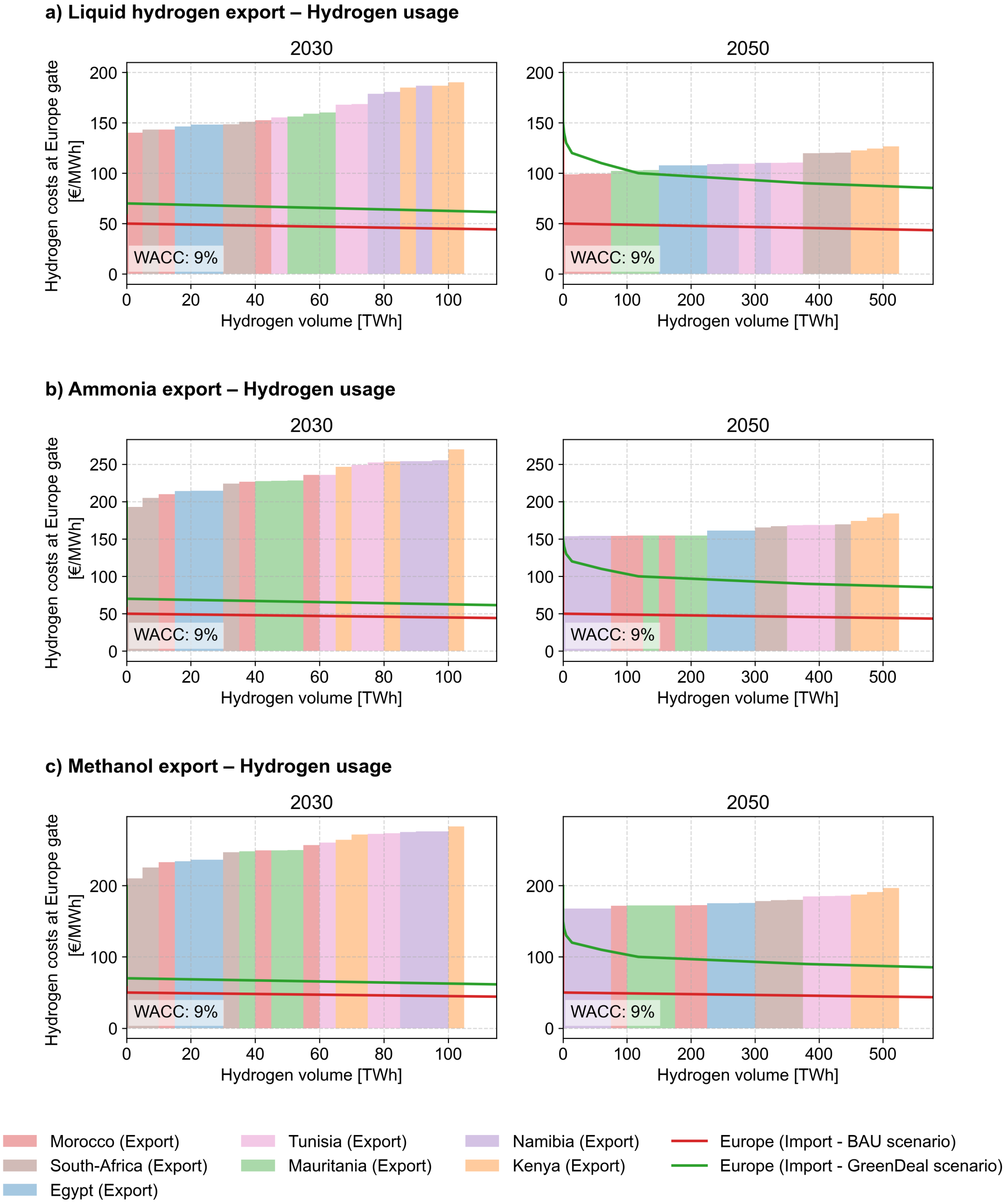


Supplementary Figure 26: European-African energy exchange of hydrogen under different shipping pathways. Liquefied hydrogen, ammonia and methanol pathways include hydrogen reconversion. For Europe, the willingness to pay for green energy imports under the GreenDeal and Business-as-Usual (BAU) scenario is shown, assuming a weighted average cost of capital (WACC) of 7%. For African countries, the willingness to accept for green energy exports of 5, 10 and 15 TWh in 2030 and 25, 50 and 75 TWh in 2050 are shown, assuming a WACC of 8%. Comparing both results indicates funding, savings and the role of the H2Global mechanism.

Supplementary Results: European-African energy exchange and the H2Global mechanism – 9% WACC

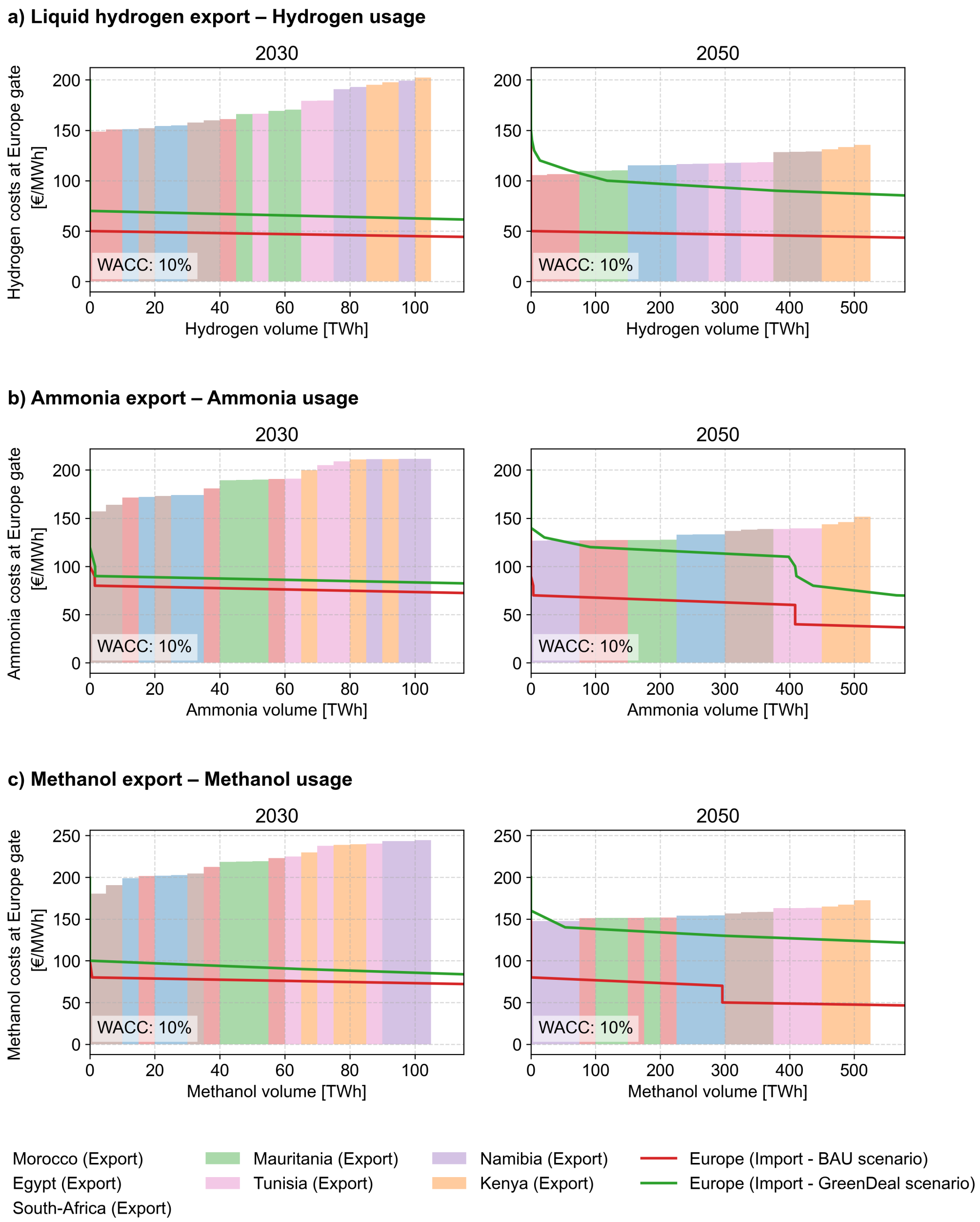


Supplementary Figure 27: European-African energy exchange of hydrogen, ammonia, and methanol. For Europe, the willingness to pay for green energy imports under the GreenDeal and Business-as-Usual scenario (BAU) is shown, assuming a weighted average cost of capital (WACC) of 7%. For African countries, the willingness to accept for green energy exports of 5, 10 and 15 TWh in 2030 and 25, 50 and 75 TWh in 2050 are shown, assuming a WACC of 9%. Comparing both results indicates funding, savings and the role of the H2Global mechanism.

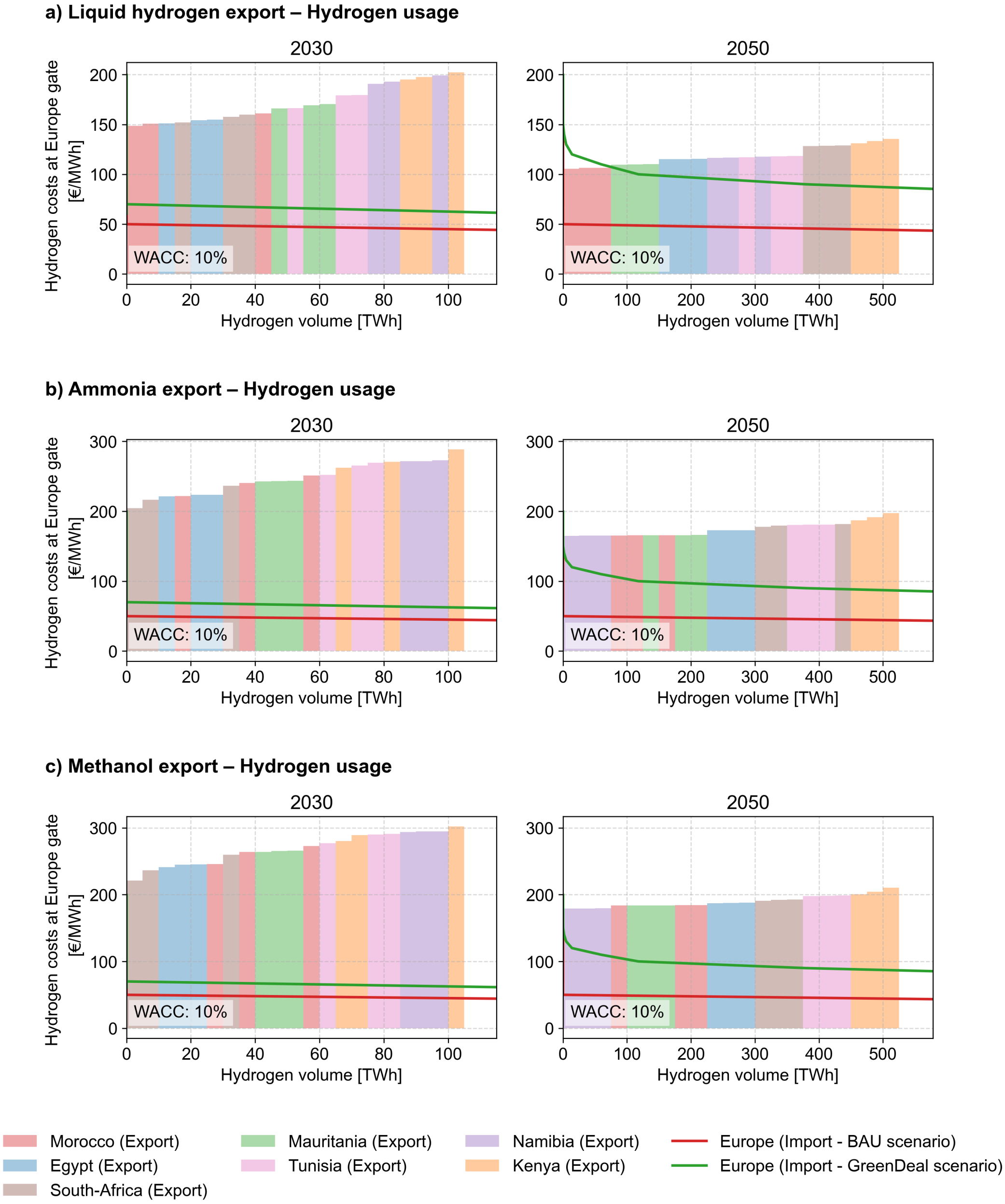


Supplementary Figure 28: European-African energy exchange of hydrogen under different shipping pathways. Liquefied hydrogen, ammonia and methanol pathways include hydrogen reconversion. For Europe, the willingness to pay for green energy imports under the GreenDeal and Business-as-Usual (BAU) scenario is shown, assuming a weighted average cost of capital (WACC) of 7%. For African countries, the willingness to accept for green energy exports of 5, 10 and 15 TWh in 2030 and 25, 50 and 75 TWh in 2050 are shown, assuming a WACC of 9%. Comparing both results indicates funding, savings and the role of the H2Global mechanism.

Supplementary Results: European-African energy exchange and the H2Global mechanism – 10% WACC



Supplementary Figure 29: European-African energy exchange of hydrogen, ammonia, and methanol. For Europe, the willingness to pay for green energy imports under the GreenDeal and Business-as-Usual (BAU) scenario is shown, assuming a weighted average cost of capital (WACC) of 7%. For African countries, the willingness to accept for green energy exports of 5, 10 and 15 TWh in 2030 and 25, 50 and 75 TWh in 2050 are shown, assuming a WACC of 10%. Comparing both results indicates funding, savings and the role of the H2Global mechanism.



Supplementary Figure 30: European-African energy exchange of hydrogen under different shipping pathways. Liquefied hydrogen, ammonia and methanol pathways include hydrogen reconversion. For Europe, the willingness to pay for green energy imports under the GreenDeal and Business-as-Usual (BAU) scenario is shown, assuming a weighted average cost of capital (WACC) of 7%. For African countries, the willingness to accept for green energy exports of 5, 10 and 15 TWh in 2030 and 25, 50 and 75 TWh in 2050 are shown, assuming a WACC of 10%. Comparing both results indicates funding, savings and the role of the H2Global mechanism.

Supplementary References

[1] F. Neumann, J. Hampp, T. Brown, Green energy and steel imports reduce Europe's net-zero infrastructure needs, Nature communications 16 (1) (2025) 5302. doi:10.1038/s41467-025-60652-1.

[2] H. Abdel-Khalek, L. Schumm, E. Jalbout, M. Parzen, C. Schauß, D. Fioriti, PyPSA-Earth sector-coupled: A global open-source multi-energy system model showcased for hydrogen applications in countries of the Global South, Applied Energy 383 (2025) 125316. doi:10.1016/j.apenergy.2025.125316.

[3] Eurostat, Chemicals production and consumption statistics. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Chemicals_production_and_consumption_statistics

[4] Eurostat, Statistics on the production of manufactured goods. https://ec.europa.eu/eurostat/databrowser/explore/all/icts?sort=category&lang=en&subtheme=prom&display=list