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M.A. dissertation defense

Clean hydrogen supplier selection using multi criteria decision making: Who do we buy our future energy from? A review and analysis

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Clean hydrogen supplier selection using multi criteria decision making

Contents

Research background and imperative

High need for clean hydrogen in South Korea	
South Korea's heavy industry and high emissions demand a shift from fossil fuels.	Reduced emissions and fossil fuel reliance, especially those related to hard-to-abate sectors
Balancing economic growth with emission reduction is a challenge	Overcoming renewable energy limitations, such as intermittency or transferability concerns
Limited renewable energy options due to geography and public support	Versatility and integration to be used from transportation to heating

Clean hydrogen offers South Korea a promising path for a sustainable and adaptable energy future

Current status quo of global hydrogen

Early Development: The global hydrogen economy is still in its infancy.

Advantages: Clean hydrogen offers reduced emissions, adaptability, and potential for heavy industry applications.

Challenges: Low production efficiency of clean hydrogen, high technology costs, inadequate infrastructure, safety concerns, and lack of clear standards for clean hydrogen hinder widespread adoption.

Countries are actively exploring hydrogen options

China has identified it as one of six key energy sources in its 2060 energy strategy (Qiu et al., 2021)

Japan is exploring hydrogen's role in its 2050 power generation mix (Matsuo et al., 2018).

Lack of global market for clean hydrogen

Technical hurdles
Standardization issues
Safety concerns

→ Sluggish development of global hydrogen market

Development of South Korean hydrogen policies

2019. 01.
Roadmap to vitalize hydrogen economy

2040 goals
Demand: H_2 vehicles (620 mil)
Demand: H_2 fuel cells (17.1 GW)
Supply: 526 MT
Price: 3,000KRW/kg

2019. 04.
Roadmap for hydrogen standardization

2019. 05.
Introduction of first international hydrogen standard

2019. 06.
Third basic energy plan

2019. 06.
Third basic energy plan

Market promotion
H_2 vehicles and fuel cells
Establish H_2 industry ecosystem

2019. 10.
Plan to build H_2 infrastructure and charging stations

Roadmap for H_2 technology

Strategy for future vehicles

Plan for regulatory innovation in new industries

Seoul conference of the International H_2 Fuel Cell Partnership (IPHE)

2019. 12.
Comprehensive plan for H_2 safety and control

2020. 01.
Legislation of Hydrogen Economy Promotion and Hydrogen Safety Management Act

2020. 07.
First Korean Hydrogen Council meeting

2020. 07.
Progress check and updates for Roadmap for H_2 technology

Progress check on H2 vehicles and infrastructure development

Strategy for H_2 city development

Korean New Deal Plan

2020. 10.
Diffusion strategy for future vehicles and market penetration

Second Korean Hydrogen Council meeting

2021. 03.
Second Korean Hydrogen Council meeting

2021. 04.
H_2 storage as key technology for net zero 2050

Subsidies for charging stations to purchase H2 fuel

2021. 11.
Basic Plan for the Implementation of the Hydrogen Economy

Fourth Korean Hydrogen Council meeting

2022. 11.
Fifth Korean Hydrogen Council meeting

H2 safety manual by Ministry of Employment and Labor

2022. 12.
Meeting for hydrogen power generation bidding market

2023. 04.
First basic national plan for carbon neutrality and green growth

2023. 05.
Hydrogen Safety Management Roadmap 2.0

2023. 06.
Regulations for hydrogen power generation bidding market

2023. 11.
Plan to implement Clean Hydrogen Portfolio Standards (CHPS)

2023. 12.
Sixth Korean Hydrogen Council meeting

Research importance

With recent advancements in CHPS, South Korea urgently needs to evaluate potential supplier countries to meet its policy requirements

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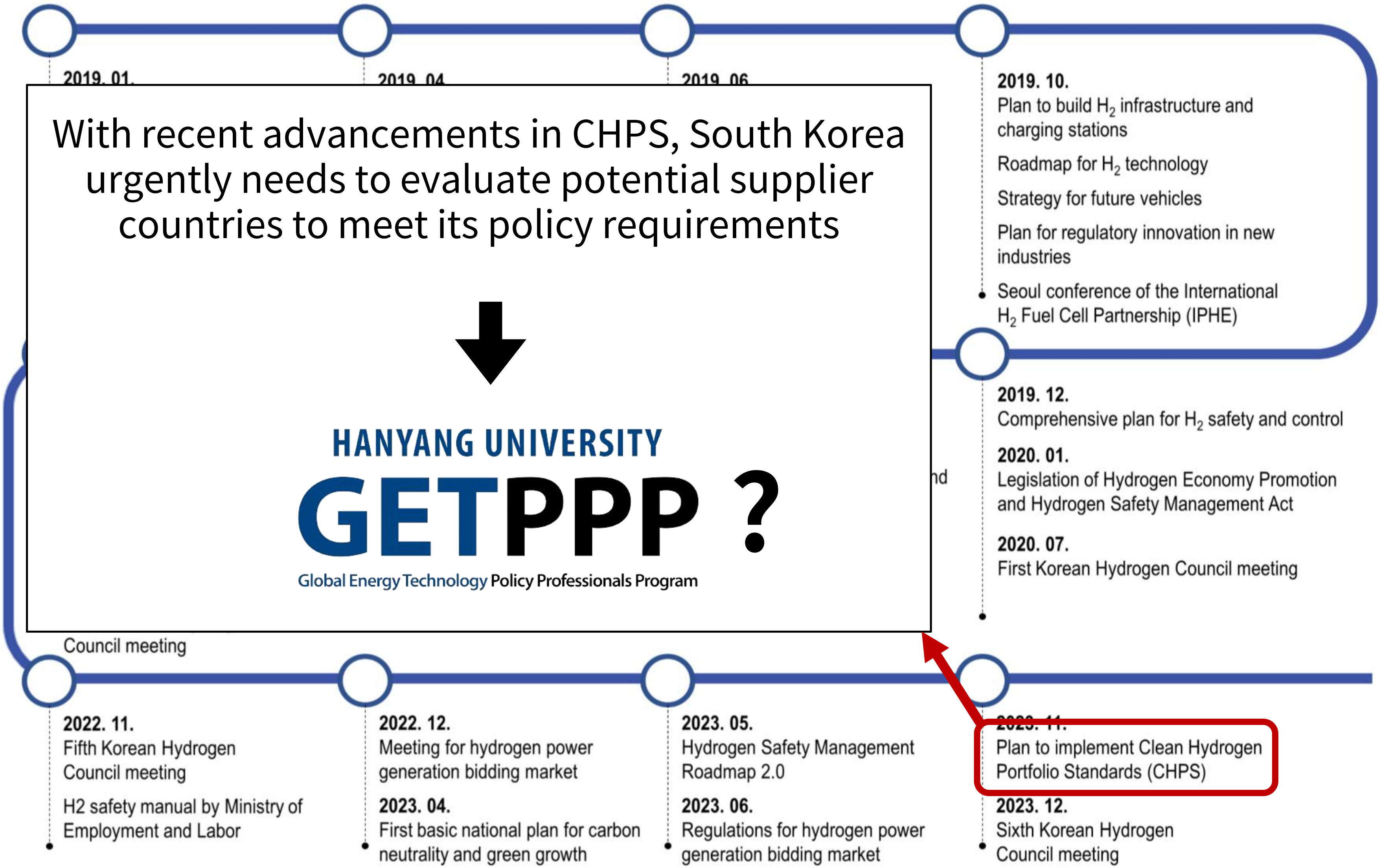
GETPPP ?

Global Energy Technology Policy Professionals Program



Research question

1. South Korea, as seen through its recent hydrogen policy directivity, is seeking immediate clean hydrogen supply to stimulate its H_2 infrastructure

2. However, as South Korea is not a suitable country for renewable energy production, we need to explore options to import hydrogen

3. What standards should guide our evaluation of potential energy suppliers for strategic partnerships down the road?

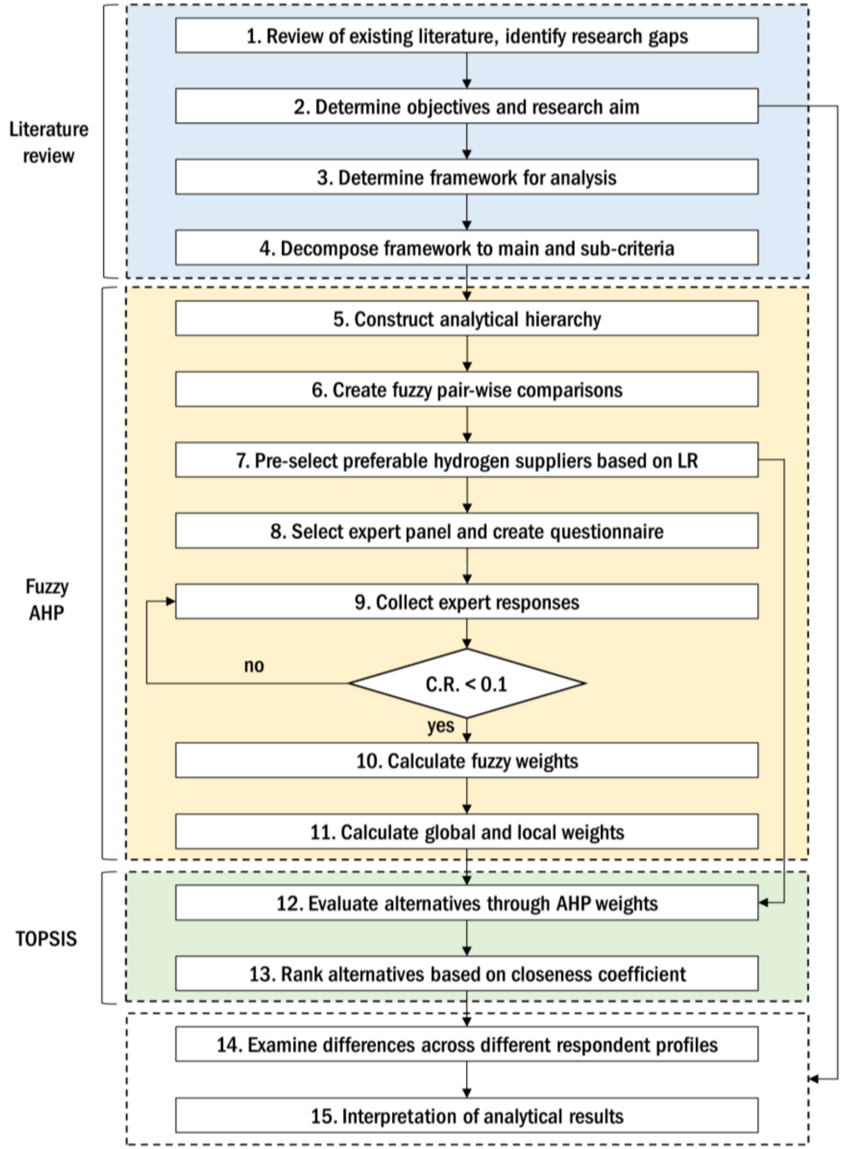
Throughout our operations at HYU, how did we select our GETPPP students?

Literature gap: There is a current lack of clean hydrogen supplier selection research at a national level

Research question

RQ1. What should South Korea consider when selecting clean hydrogen suppliers?
RQ2. How would experts compare the different categories?
RQ3. Based on the created criteria, what trans-Pacific countries are most suited for the clean hydrogen supply chain?

Research outline



Literature review: How did the global energy supply chain develop? What should we consider based on its development

Requires a comprehensive framework that evaluates all ends → **PESTLE framework**

Political, Economic, Social, Technological, Legal, Environmental

What criteria under PESTLE, should we weight higher? → AHP pairwise comparison

Collect expert opinions, use fuzzy sets to reduce subjectivity, and check for internal consistency errors

Based on the identified preferences, evaluate <u>best possible supplier countries</u> using TOPSIS

Pre-selection of ideal countries through structured literature review

Evolution of the global energy supply chain

Coal

Coal fueled nations' might & money (Gedik et al., 2014)
Mines: warfare targets for control (Greasley, 1991)
Long-distance transport vulnerable (Alexander, 2008)
War disrupted coal flow & trade (Ediger & Bowlus, 2019; Kramer, 2014)
Governments controlled & secured (Oleh & Oleh, 2019)

Crude oil

Concentrated production (Mid East) (Hamilton, 2009)
OPEC controls oil price & flow (Dées et al., 2007)
More energy per unit than coal (Zhang et al., 2021)
Versatile fuel: gasoline, diesel, jet fuel (Hamilton, 1983)
Vulnerable to Mideast instability (Jones & Kaul, 1996)
Choke points: Strait of Hormuz (Thia-Eng et al., 2000)
1970s: Price spike due to politics (Mazarei Jr, 1996)

Nuclear and shale gas

Nuclear Power:
Cleaner option, but safety fears (Chernobyl, Fukushima) (Park et al., 2013)
Public trust needs strong safety measures (regulations)

Shale gas:
Fracking technologies unlocks cleaner-burning gas (Enayatpour et al., 2019)

Renewable energy

Intermittency: Production doesn't always align with peak demand (Wang et al., 2008).
Grid Dependence: Limited mobility compared to fossil fuels.

Critical Mineral Supply Chain Risks
→ Hydrogen as a long term solution

Evolution of the global energy supply chain

Coal

Crude oil

Strategic Importance: Coal fueled national security, economic stability, and geopolitical power (Gedik et al., 2014). Control over coal mines became a key objective during conflicts (Greasley, 1991).

Vulnerable Supply Chains: Transportation of coal over long distances by rail, barge, and ship faced disruptions from wars, infrastructure damage, and logistical bottlenecks (Alexander, 2008).

Government Intervention: Governments often controlled or heavily regulated coal industries to prioritize coal distribution during wars. Nationalization of mines ensured efficient production for war efforts (Ediger & Bowlus, 2019).

Strategic Infrastructure: Railways, crucial for coal transport, became targets during conflicts. Maintaining secure transportation infrastructure was critical (Oleh & Oleh, 2019).

Disrupted International Trade: Naval blockades and warfare disrupted international coal trade, forcing diplomatic maneuvering for energy supplies (Kramer, 2014). Germany's struggle to secure coal during WWI due to a British blockade exemplifies this vulnerability.

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→ Hydrogen as a long term solution

Evolution of the global energy supply chain

Coal

Crude oil

Unlike coal, oil reserves are concentrated in specific regions, with the Middle East dominating (Hamilton, 2009).
Countries like Saudi Arabia, Iraq, and Iran control a significant share of global oil, giving them leverage over the market (Hamilton, 2009).
OPEC, a cartel of oil-producing countries, can dictate oil prices and production, impacting the global economy (Dées et al., 2007).

Advantages of Oil:

Higher energy density, leading to efficient transportation and power generation (Zhang et al., 2021).
Easier transport through pipelines compared to bulkier coal (Zhang et al., 2021).
Versatility: refining into gasoline, diesel, and jet fuel for various industries (Hamilton, 1983).
Cleaner burning than coal, though environmental concerns still existed (Hamilton, 1983).

Vulnerability of Oil Dependence:

Reliance on the Middle East creates vulnerabilities due to political instability (Jones & Kaul, 1996).
Oil distribution depends on critical choke points like the Strait of Hormuz (Thia-Eng et al., 2000).
The 1970s energy crises exemplified the precariousness of relying on politically unstable regions (Mazarei Jr, 1996).
Dependence on a volatile region for a critical resource led to market instability and push for alternatives (Kang et al., 2017).

Fracking technologies unlocks cleaner-burning gas (Enayatpour et al., 2019)

→ Hydrogen as a long term solution

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Fracking technologies unlocks cleaner-burning gas
(Enayatpour et al., 2019)

Rising oil prices and growing environmental concerns spurred a shift away from traditional fossil fuels like coal and oil (Jacobson, 2009).

Nuclear Power:

A cleaner alternative offering high energy density (Jacobson, 2009). However, safety concerns linger due to high-profile accidents like Chernobyl and Fukushima (Park et al., 2013).

Enhanced regulations, robust safety protocols, and international cooperation on non-proliferation are crucial for public acceptance and responsible use (Taremi, 2005).

Shale Gas Revolution:

Technological advancements in hydraulic fracturing (fracking) unlocked previously inaccessible natural gas reserves in shale formations (Enayatpour et al., 2019).

Shale gas burns cleaner than coal for electricity generation, promoting diversification and reducing reliance on traditional fossil fuels.

→ Hydrogen as a long term solution

Evolution of the global energy supply chain

The global energy landscape is shifting towards net zero emissions, driven by the increasing cost-competitiveness and technological advancements of renewable energy sources like solar and wind (Gielen et al., 2019).

Intermittency: Production doesn't always align with peak demand (Wang et al., 2008).

Solar farms and wind turbines are built closer to consumers, creating new challenges:

Critical Mineral Supply Chains: Essential minerals like lithium and nickel are concentrated in a few countries, raising concerns about potential bottlenecks and vulnerabilities similar to the oil crises of the 1970s (Hwang et al., 2017; Gulley et al., 2018).

Hydrogen as a Long-Term Solution:

Hydrogen offers versatility as a fuel, storage medium, and energy carrier.

Hydrogen complements renewable energy by addressing some of its limitations.

Crude oil

oncentrated production (Mid East) (Hamilton, 2009)
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Renewable energy

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→ Hydrogen as a long term solution

Evolution of the global energy supply chain

P E S T L E

Coal
- Political: Geopolitical control, energy security concerns
- Technological: N/A (Mature technology)
- Environmental: High emissions, resource depletion, air and water pollution

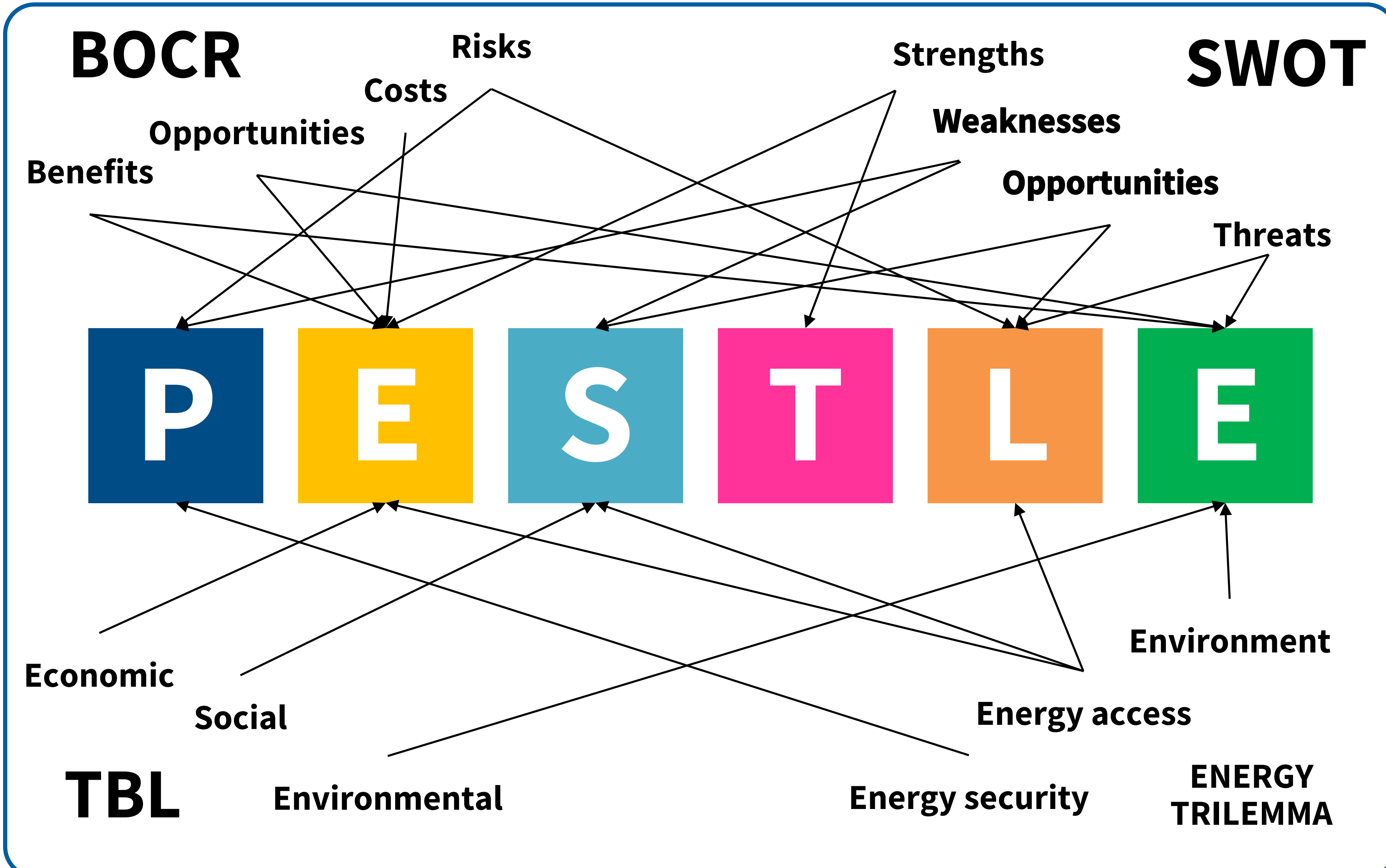
Shale gas
- Economic: Cost-competitive (compared to fossil fuels)
- Technological: Fracking technology advancements
- Environmental: Lower emissions than coal, but still a fossil fuel with environmental impact

Nuclear
- Political: Non-proliferation treaties
- Social: Public perception of safety
- Technological: Limited technological advancements
- Legal: Non-proliferation agreements, safety standards

Crude oil
- Political: Geopolitical control by major oil producers, energy security concerns
- Economic: Market dominance (OPEC), volatile prices due to political instability
- Technological: Advanced exploration and extraction techniques
- Legal: Trade policies impacting oil prices

Renewable energy
- Economic: Cost-competitive advancements
- Social: Public support for environmental initiatives
- Technological: Renewable energy advancements
- Legal: Environmental compliance
- Environmental: Low emissions, sustainable resource

Comparison to other relevant frameworks



Current coverage of clean hydrogen literature

Reviews on clean hydrogen literature

Sources	**Attributes**						
	P	E	S	T	L	E	Tools and methodologies
Akhtar et al. (2023)		●		●	●	○	LCA
Cetinkaya et al. (2012)		○		●		●	LCA
Gemechu et al. (2016)	○	●	●		●	●	LCA
Kolotzek et al. (2018)	●		●			●	AHP
Kumar et al. (2022)		●	●		○	●	Fuzzy-AHP, TOPSIS
Law and Pagilla (2021)	○	●	●		○	●	Scenario analysis
Narula et al. (2021)		●	●	○		●	Fuzzy-AHP
Rahimirad and Sadabadi (2023)	○	○		○		●	Fuzzy TOPSIS, VIKOR, SWOT
Wulf et al. (2018)		●		○	○	●	LCA

Notes: ●=direct relevance, ○=indirect relevance.

Scopus

PESTLE AND AHP

None for clean hydrogen and supplier selection

- **Indicators for circular economy,** ***Management Decision***
- **Renewable energy sector,** ***Utilities Policy***
- **Transportation modes of developing cities,** ***Transportation Research A***
- **Regional center selection,** ***Global Business Review***

Development of supplier selection research

Supplier selection using multi criteria decision making, has primarily focused on firm level analysis → B2B relationships

- More practical as actual trade relations occur at the business level
- Allows for more accurate assessment of suppliers and alternatives

However, public goods, such as energy resources and critical material are often governed by governments or institutional regulations → Country level examination required

- Therefore, supplier selection concerning such strategic goods are gradually being examined based on the suppliers' nationality (Mastrocinque et al., 2020)

Selection of methodology: Fuzzy AHP + TOPSIS to examine clean hydrogen suppliers at national level

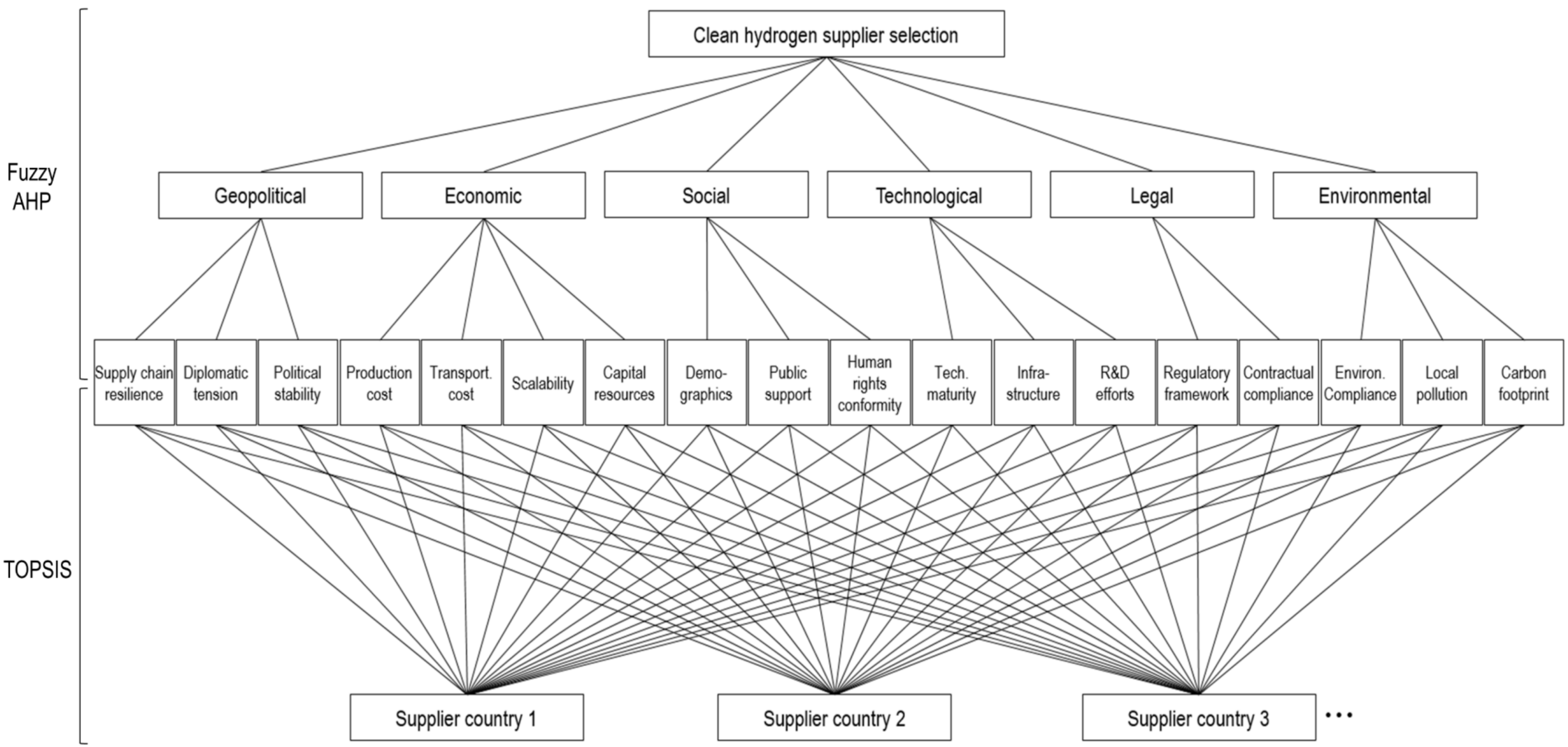
Supplier selection commonly utilizes MCDM tools, particularly AHP, TOPSIS, DEMATEL, VIKOR, COPRAS, etc.

Due to lack of actual data, given the infant development of the global hydrogen market, MCDM is appropriate

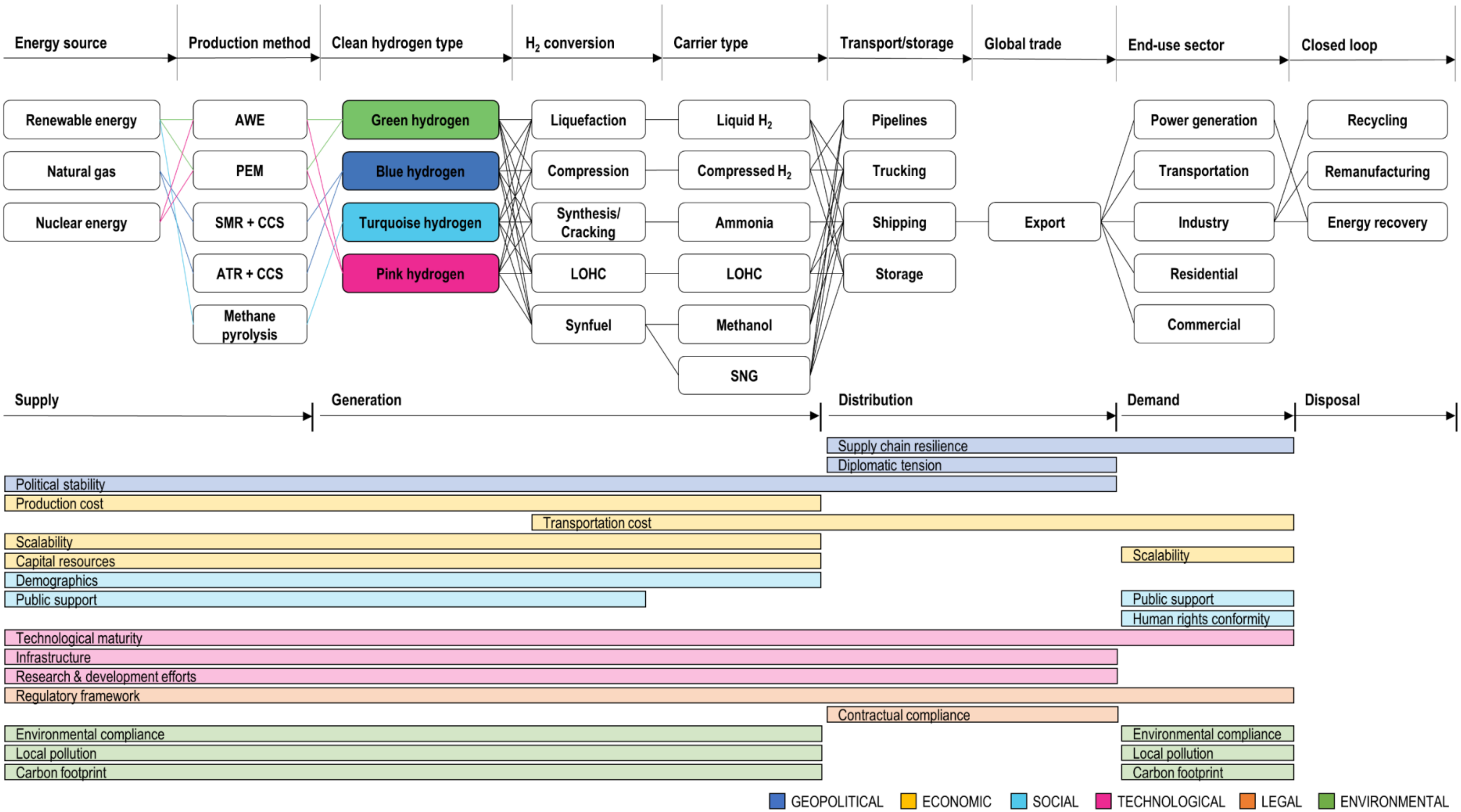
Scale item development

	Scale items	References
P	Supply chain resilience	(Karatop et al., 2021; Liu et al., 2023; Ponomarov & Holcomb, 2009)
	Diplomatic tension	(Lee & Song, 2023)
	Political stability	(Bhatnagar & Sohal, 2005; Chan & Kumar, 2007; Khan et al., 2019)
E	Production cost	(Chan & Kumar, 2007; Chung et al., 2014; Pilavachi et al., 2009)
	Transportation cost	(Pilavachi et al., 2009; Solangi et al., 2021)
	Scalability	(Chung et al., 2014; Prateep Na Talang & Sirivithayapakorn, 2020)
S	Capital resources	(Manirambona et al., 2022; Solangi et al., 2021)
	Demographics	(Kaya & Kahraman, 2010; Yang et al., 2024)
	Public support	(Manirambona et al., 2022; Yang et al., 2024)
T	Human rights protection	(Chan & Kumar, 2007; Kumar et al., 2020)
	Technological maturity	(Black et al., 2015; Kaya & Kahraman, 2010; Manirambona et al., 2022)
	Infrastructure	(Black et al., 2015; Yang et al., 2024)
L	R&D efforts	(Karatop et al., 2021; Yang et al., 2024)
	Regulatory framework	(Black et al., 2015; Yang et al., 2024)
	Contractual compliance	(Wagner & Bode, 2008)
E	Environmental compliance	(Kumar et al., 2020; Yang et al., 2024)
	Local pollution	(Karatop et al., 2021; Kaya & Kahraman, 2010)
	Carbon footprint	(Black et al., 2015; Kaya & Kahraman, 2010; Manirambona et al., 2022).

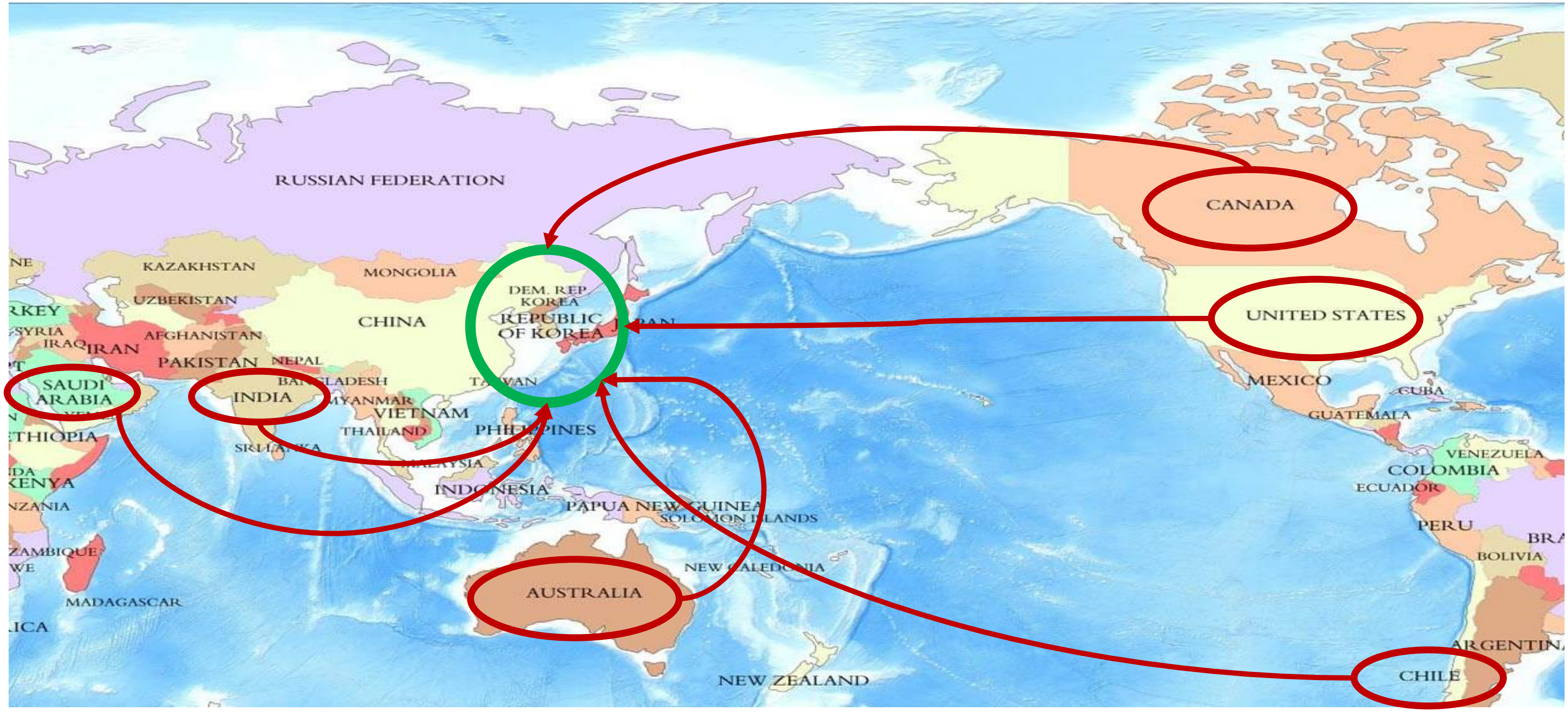
Developed AHP model



Clean hydrogen supply chain and PESTLE



Supplier pre-selection



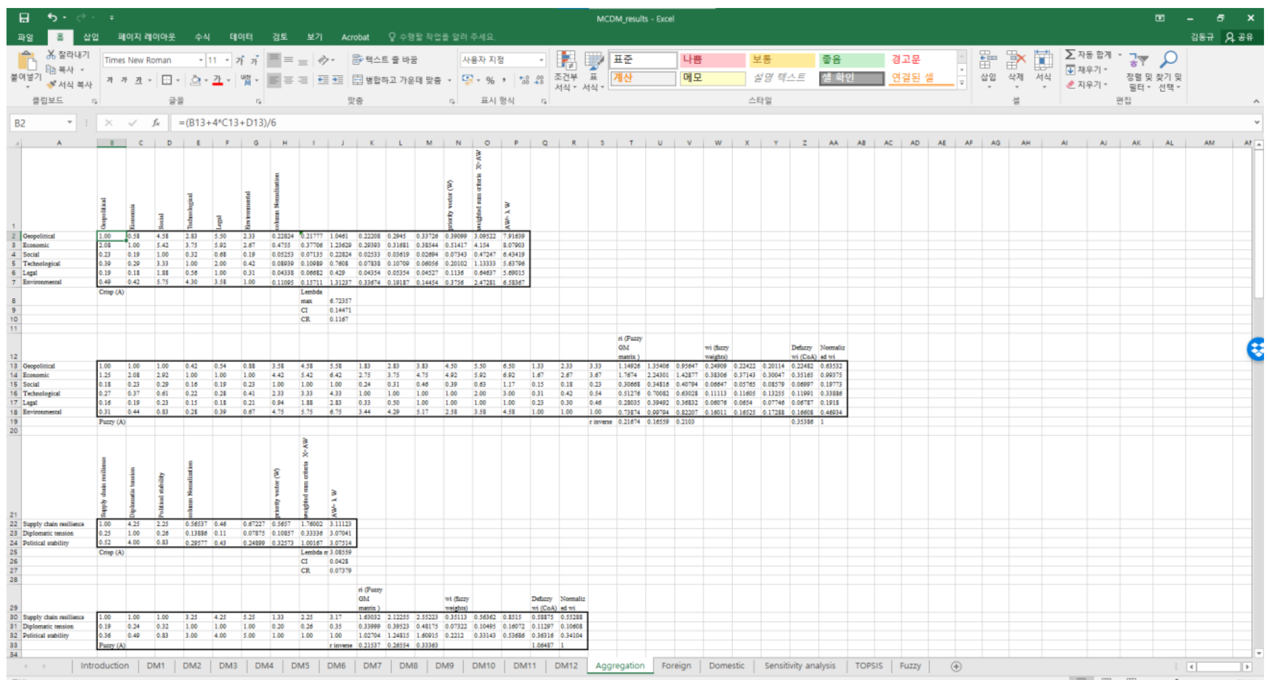
Reference	Source	High potential hydrogen partners										
		AUS	BRA	CAN	CHL	CHN	GER	IND	JAP	RUS	SDA	USA
Jang et al. (2023)	IIT	◎	○	◎	◎	◎	◎	○	◎		◎	◎
Kim (2022)	KEEI	◎		◎	◎	△	○		◎	◎	◎	◎
Lee (2022)	KIET	◎	○	◎	◎		◎	○	△	△	◎	◎
Bae et al. (2022)	KOTRA	◎		○	○	◎	◎	○	◎	△	○	◎

Notes: ◎=highly strategic partner, ○=moderately important partner, △=high potential, but with complications

Sample and data analysis

Variables	Category	Frequency (N=12)	Percent (%)
Nationality	Korean	6	50.0
	Foreign*	6	50.0
Field	Government	4	33.3
	Public sector	4	33.3
	Private sector	4	33.3
Work experience	Less than 5 years	2	16.7
	5 to 10 years	5	41.7
	10 to 20 years	4	33.3
	20 to 30 years	1	0.83

All data was processed with Microsoft Excel



Analytical results (fuzzy AHP)

AHP results for main criteria

	1. GE	2. EC	3. SO	4. TE	5. LE	6. EN	Weight	Rank
GE	(1.00, 1.00, 1.00)	(0.27, 0.38, 0.64)	(3.08, 4.08, 5.08)	(1.33, 2.33, 3.33)	(4.08, 5.08, 6.08)	(1.83, 2.83, 3.83)	0.540	2
EC	(1.67, 2.67, 3.67)	(1.00, 1.00, 1.00)	(4.08, 5.08, 6.08)	(3.00, 4.00, 5.00)	(5.08, 6.08, 7.08)	(1.33, 2.33, 3.33)	1.060	1
SO	(0.20, 0.25, 0.33)	(0.16, 0.20, 0.25)	(1.00, 1.00, 1.00)	(0.25, 0.33, 0.49)	(0.33, 0.49, 0.96)	(0.14, 0.16, 0.20)	0.207	5
TE	(0.31, 0.44, 0.83)	(0.20, 0.25, 0.33)	(2.08, 3.08, 4.08)	(1.00, 1.00, 1.00)	(1.00, 2.00, 3.00)	(0.16, 0.20, 0.25)	0.340	4
LE	(0.16, 0.20, 0.25)	(0.14, 0.16, 0.20)	(1.08, 2.08, 3.08)	(0.33, 0.50, 1.00)	(1.00, 1.00, 1.00)	(0.20, 0.25, 0.33)	0.195	6
EN	(0.27, 0.37, 0.61)	(0.31, 0.44, 0.83)	(5.08, 6.08, 7.08)	(4.08, 5.08, 6.08)	(3.08, 4.08, 5.08)	(1.00, 1.00, 1.00)	0.465	3

AHP results for scale items

	Criteria W	Scale items	Local W	Global W	Rank
GE	0.540	Supply chain resilience	0.596	0.322	2
		Diplomatic tension	0.105	0.057	13
		Political stability	0.299	0.161	7
EC	1.060	Production cost	0.198	0.210	5
		Transportation cost	0.068	0.072	12
		Scalability	0.580	0.615	1
		Capital resources	0.154	0.163	6
SO	0.207	Demographics	0.710	0.147	9
		Public support	0.198	0.041	15
		Human rights conformity	0.093	0.019	18
TE	0.340	Technological maturity	0.234	0.080	11
		Infrastructure	0.700	0.238	4
		R&D investment	0.066	0.023	17
LE	0.195	Regulatory framework	0.785	0.153	8
		Contractual compliance	0.215	0.042	14
EN	0.465	Environmental compliance	0.288	0.134	10
		Local pollution	0.079	0.037	16
		Carbon footprint	0.634	0.294	3

Lambda max=6.724, CI=0.145, CR=0.117

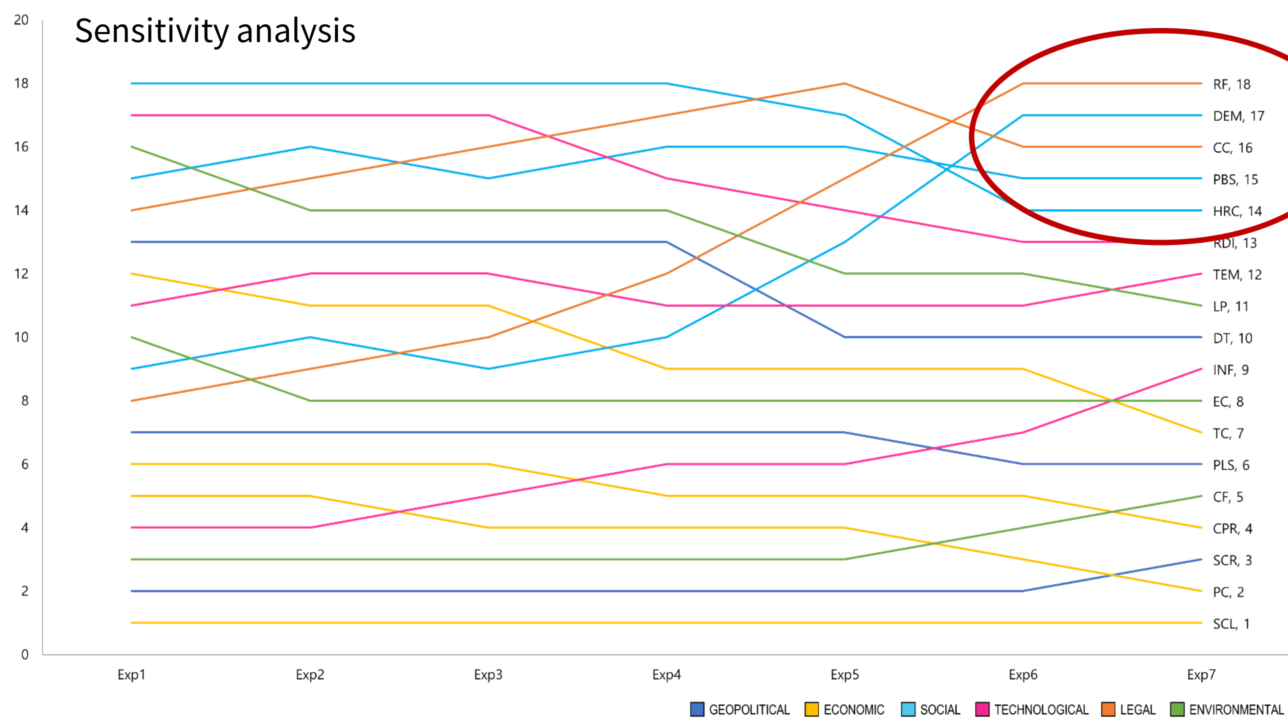
Comparative and sensitivity analysis

Foreign

	1. GE	2. EC	3. SO	4. TE	5. LE	6. EN
1. GE	**1.00**	0.40	4.00	2.33	5.00	2.67
2. EC	0.40	**1.00**	5.00	4.00	6.00	2.33
3. SO	4.17	5.17	**1.00**	0.35	0.56	0.17
4. TE	2.33	4.00	0.33	**1.00**	2.00	0.20
5. LE	5.17	6.17	0.52	2.00	**1.00**	0.26
6. EN	3.00	2.33	0.16	0.20	0.25	**1.00**

Domestic

*No significant difference found between panel nationality



Legal and social factors, tend to be effected largely in sensitivity analysis

In general, the model is not highly sensitive

Analytical results (TOPSIS)

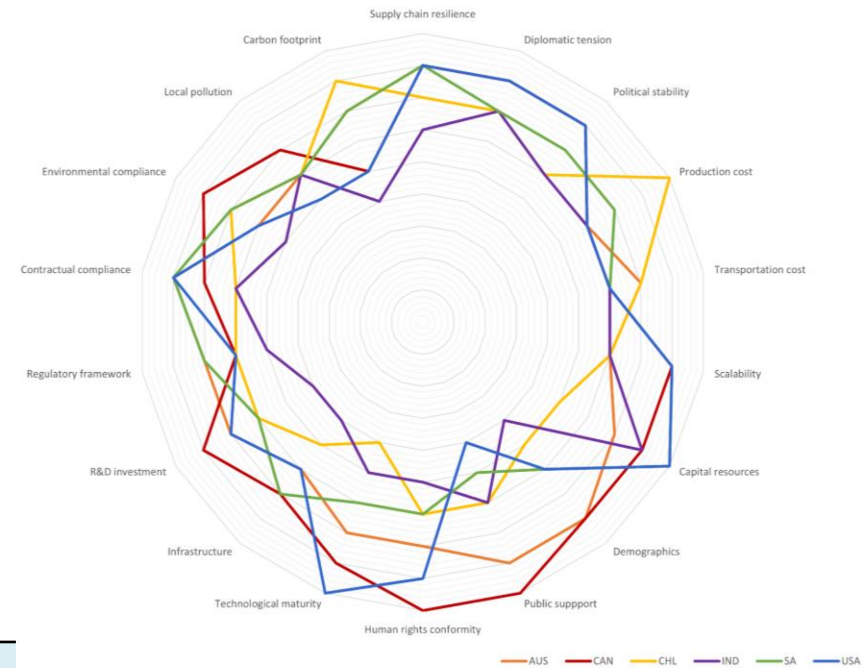
Scale item	Supplier country						Separation	
	AUS	CAN	CHL	IND	SA	USA	MAX	MIN
Supply chain resilience	0.056	0.061	0.052	0.046	0.051	0.056	0.061	0.046
Diplomatic tension	0.010	0.011	0.009	0.008	0.008	0.011	0.011	0.008
Political stability	0.031	0.031	0.023	0.022	0.024	0.030	0.031	0.022
Production cost	0.032	0.031	0.047	0.031	0.034	0.034	0.047	0.031
Transportation cost	0.013	0.011	0.013	0.012	0.012	0.012	0.013	0.011
Scalability	0.097	0.120	0.086	0.093	0.101	0.118	0.120	0.086
Capital resources	0.026	0.029	0.017	0.030	0.028	0.034	0.034	0.017
Demographics	0.033	0.031	0.019	0.016	0.023	0.024	0.033	0.016
Public support	0.009	0.009	0.007	0.006	0.005	0.004	0.009	0.004
Human rights conformity	0.003	0.004	0.003	0.002	0.003	0.004	0.004	0.002
Technological maturity	0.014	0.016	0.008	0.011	0.012	0.018	0.018	0.008
Infrastructure	0.042	0.049	0.037	0.030	0.041	0.038	0.049	0.030
R&D investment	0.004	0.005	0.003	0.002	0.003	0.004	0.005	0.002
Regulatory framework	0.030	0.025	0.024	0.022	0.026	0.027	0.030	0.022
Contractual compliance	0.008	0.007	0.006	0.006	0.007	0.008	0.008	0.006
Environmental compliance	0.021	0.027	0.027	0.015	0.023	0.020	0.027	0.015
Local pollution	0.006	0.007	0.006	0.006	0.006	0.005	0.007	0.005
Carbon footprint	0.060	0.046	0.065	0.032	0.054	0.038	0.065	0.032
Positive ideal solution	0.005	0.005	0.005	0.006	0.004	0.004		
Negative ideal solution	0.004	0.005	0.003	0.001	0.003	0.003		
Relative distance	0.74	0.96	0.63	0.23	0.64	0.77		
Rank	3	1	5	6	4	2		

Canada
USA
Australia
Saudi Arabia
Chile
India

More preferable

Less preferable

Unweighted radar chart of scale items.



Discussion

Theoretical Implications:
- This research shifts the focus from firm-centric analysis to supplier selection at the country level.
- A clean hydrogen AHP framework is developed that considers PESTLE factors for a comprehensive understanding of supply chain dynamics.
- The multinational expert panel adds depth and validates the methodology.

Practical Implications:
- Policymakers: Develop innovative financing mechanisms (green bonds, hydrogen funds) and hydrogen diplomacy initiatives.
- Business Managers: Consider geopolitical risk insurance and promote localized hydrogen production hubs.
- Stakeholders: Advocate for eco-labeling systems for hydrogen products.

Limitations and Future Research:
- The dynamic energy market necessitates regular updates to the analysis.
- Subjectivity in expert judgments can be addressed by incorporating more quantitative data.
- Adding another layer to the hierarchy, and focusing deeply on each criteria may be needed.

Thank you

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