HANYANG UNIVERSITY

THE KOREAN SOCIETY OF CLIMATE CHANGE RESEARCH

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Identifying circular economy enablers in South Korea's manufacturing industry: Utilizing a multi criteria decision making analysis

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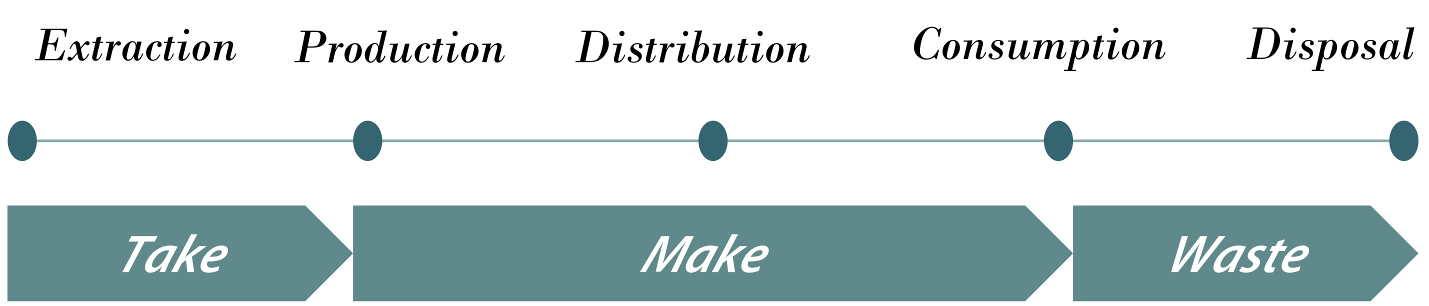
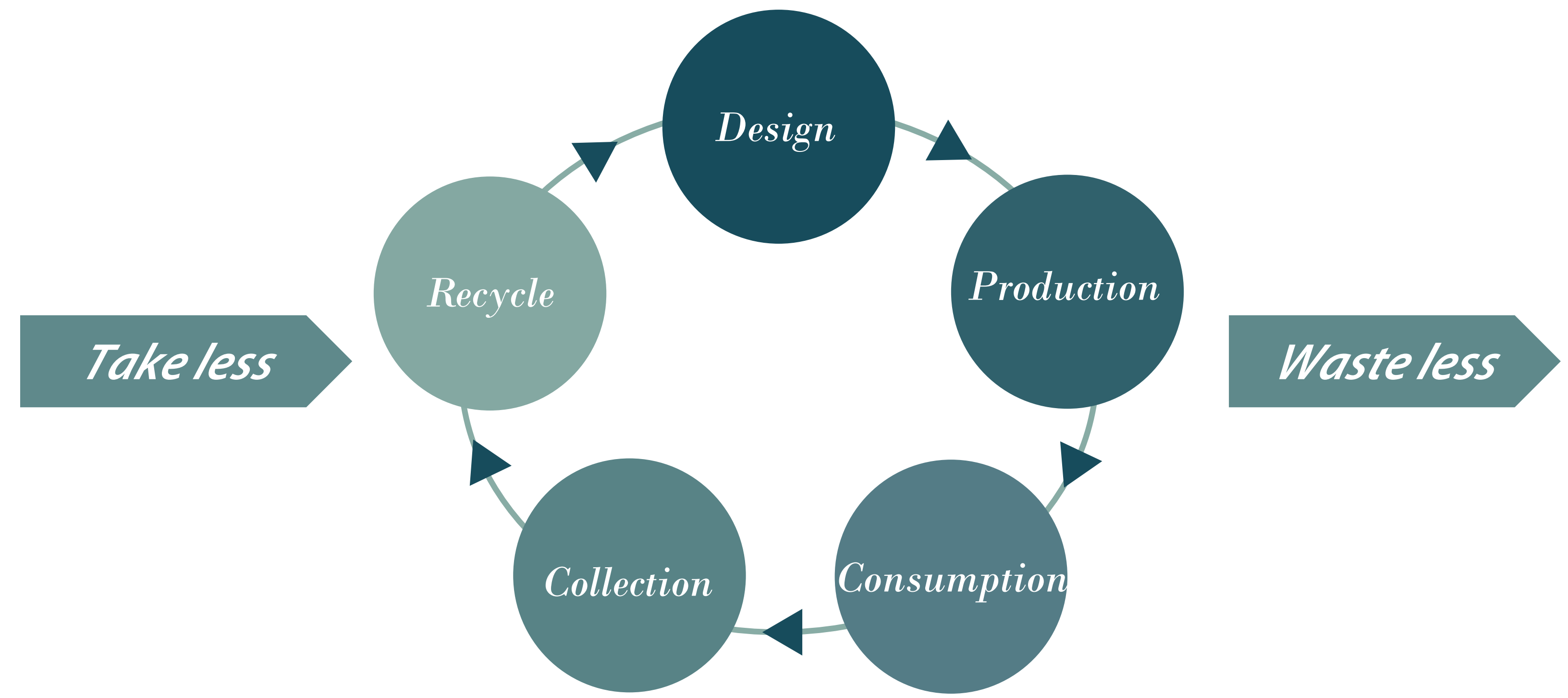
Background of circular economy (CE)

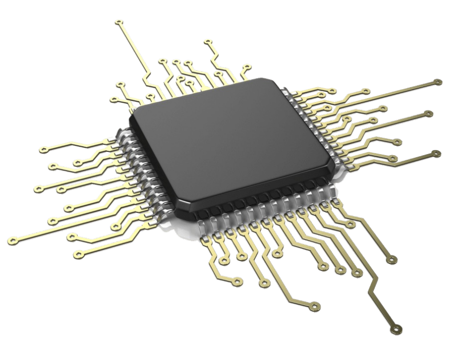
Linear economy



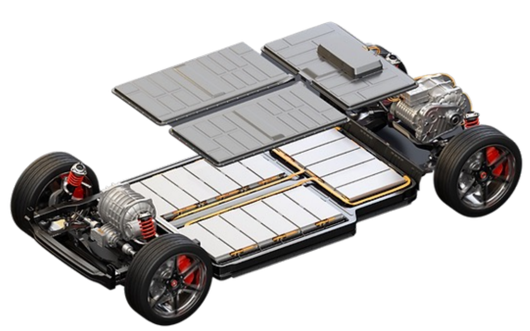
Circular economy



South Korea's manufacturing industry heavily relies on strategic resources



Semi conductors



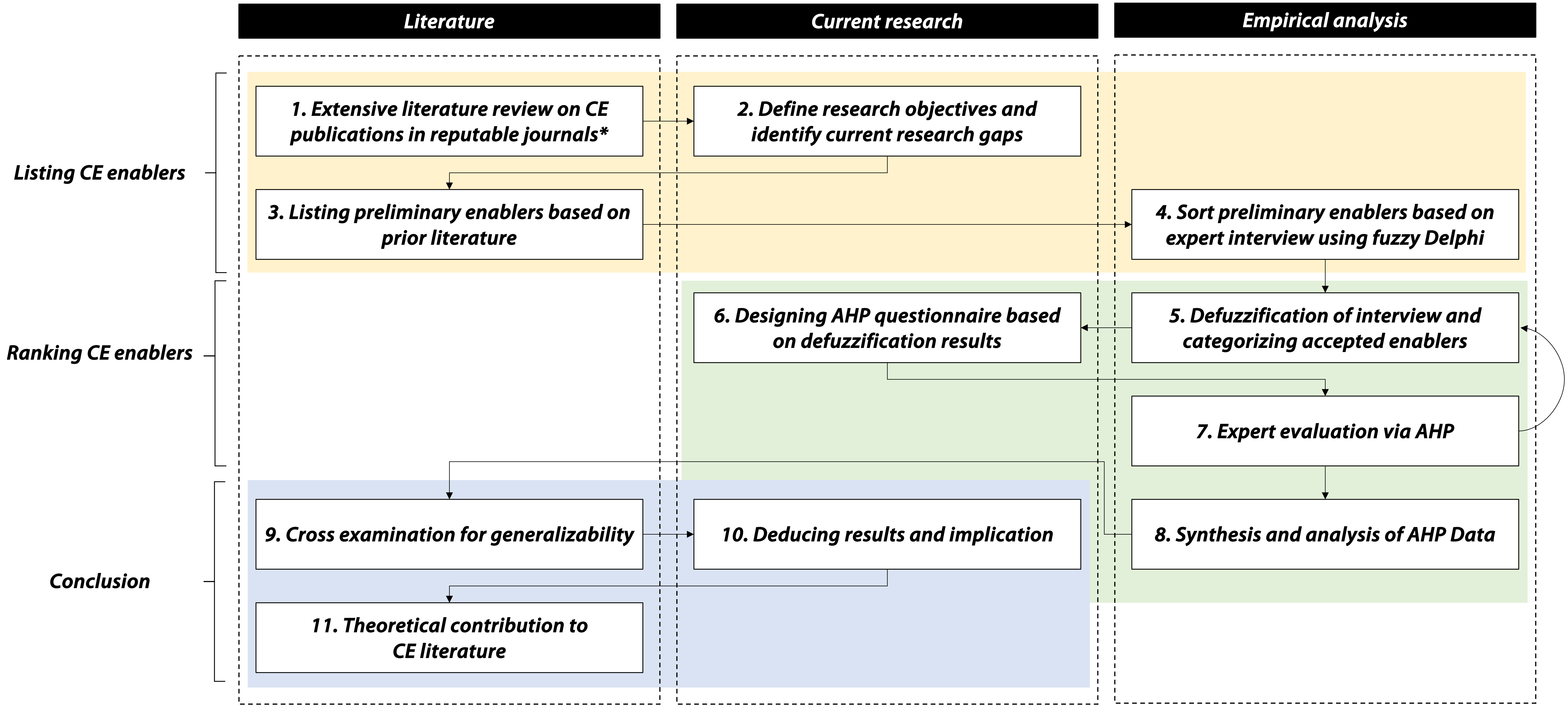
Batteries

Circular transition in South Korea is essential for its geography and economy

- *By transitioning to CE, South Korea can create new market opportunities*
- *Solve issues related to poor resource accessibility*
- *Allow more sustainable and environmental development*
- *Meet global requirements related to sourcing and recyclability*

RQ1. What are the main enablers that drive South Korea's CE transition?
RQ2. What enablers take priority over others?

Outline of research



Identifying CE enablers (1)

Regulatory enablers
(Manomaivibool and Hong 2014)

- *Extended producer responsibility (EPR) policies proven to encourage design for recyclability*
- *Studies link regulatory incentives to increased green tech adoption*
- *Regulations on material recycling shown to bolster secondary material markets*

Financial enablers
(Cohen and Gil 2021)

- *Financial incentives align corporate investments with circular economy goals*
- *Research shows tax breaks and subsidies significantly boost circular initiatives*
- *Studies find that funding for sustainable R&D spurs industry innovation.*

Socio-cultural enablers
(Xu, Qian et al. 2023)

- *Consumer awareness and values are key to driving market demand for circular products*
- *Cultural shifts towards sustainability can accelerate corporate adoption of circular practices*
- *Social norms and behaviors play a critical role in embedding circularity in economic systems.*

Environmental enablers
(Mondal, Singh et al. 2023)

- *Environmental gains, such as reduced waste, drive circular strategies*
- *Biodiversity preservation through circular practices gains academic emphasis*
- *Lifecycle assessment studies affirm circular economy's role in minimizing ecological footprints*

Identifying CE enablers (2)

Technological enablers (Alonso-Almeida, Rodriguez-Anton et al. 2021)	*Organizational enablers (Cohen and Gil 2021)*
• *Advances in recycling and remanufacturing technologies are key for resource recovery* • *Digital tools for tracking and optimizing resource use bolster circular operations* • *Innovation in material science is crucial for developing sustainable alternatives*	• *Leadership commitment to circular principles is critical for organizational transformation* • *Internal knowledge-sharing practices enhance the implementation of circular strategies* • *Cross-departmental collaboration is essential for developing and sustaining circular economy practices within organizations*
Infrastructural Enablers (Xu, Qian et al. 2023)	*Geopolitical Enablers (Zeng, Ogunseitan et al. 2022)*
• *Structured recycling and waste management infrastructure is important for effective material recovery* • *Efficient logistics and supply chain networks are key to supporting circular economy models* • *Investment in green infrastructure facilitates the transition to circular operational processes*	• *Global trade relations and geopolitical dynamics influence the flow of materials and technologies necessary for a circular economy* • *Literature suggests that geopolitical considerations can impact the effectiveness of circular economy strategies, especially in export-oriented economies like South Korea* • *However, there is a lack of studies that tackle geopolitical enablers in the manufacturing industry, especially in the context of South Korea.*

Literature review overview and research gap

Attributes								
MCDM references	*CE enablers*							
	RGE	*FNE*	*SCE*	*ENE*	*TNE*	*OGE*	*IFE*	*GPE*
Alonso-Almeida et al. (2021)	●	●	●	●		●		○
Cohen and Gil (2021)		●	●	●	○	●	●	
Patel et. al. (2021)	●	●		●	●	●	○	
Manomaivibool and Hong (2014)	●		●	○		○		○
Meili and Stucki (2023)	●	○		●	●	●		○
Mondal and Singh et. al. (2023)	●	●		○	●	●	○	
Rizos and Bryhn (2022)	●	○	○	●	●		○	●
Voukkali et. al. (2023)	●	●	●		○	○	●	
Xu et. al. (2023)	●	●	●	●		●	●	
Zeng et al. (2022)	●	○	●		●	●		○

Notes: ●=high relevance, ○=moderate relevance, (1) MCDM=multi criterion decision making, RGE=regulatory enablers, FNE=financial enablers, SCE=socio-cultural enablers, ENE=environmental enablers, TNE=technological enablers, OGE=organizational enablers, IFE=infrastructural enablers, GPE=geopolitical enablers

Geopolitical enablers are becoming more relevant

Policy and resource management

Resource allocation laws: *National policies, like the CRMA, aim to secure a stable supply of critical materials for CE, ensuring resource independence.*

Sustainable resource trade: *Trade agreements influenced by policies such as the IRA can promote or restrict the import and export of recyclable materials and sustainable resources.*

International relations and collaboration

Diplomatic CE agreements: *Diplomatic efforts can result in joint initiatives for CE, leveraging international cooperation for shared environmental progress.*

Impact of sanctions and embargoes: *Geopolitical tensions that lead to sanctions can obstruct the flow of CE technologies and critical materials between countries.*

Legislation and industrial action

Incentivizing domestic CE Practices: *The IRA encourages local industries to adopt CE practices by offering financial incentives for sustainability.*

Securing material supply chains: *The CRMA focuses on strengthening domestic production and reducing dependency on imported raw materials, crucial for a resilient CE framework.*

Preliminary enablers list

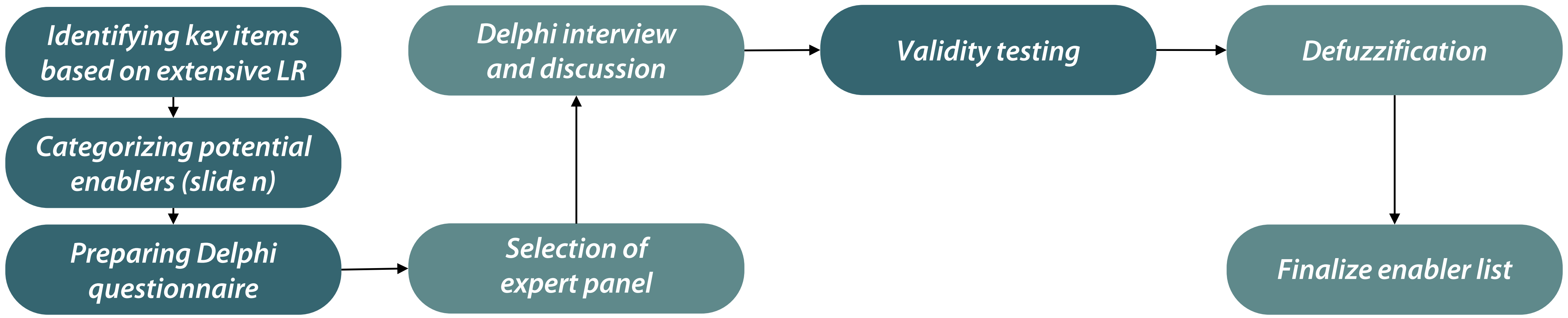
Potential circular economy enablers (simplified)					*Based on 17 relevant literature from reputable journal entries**
Category	*Code*	*Item*	*Category*	*Code*	*Item*
Regulatory	*RGE_1*	*Polluter's pay principle*	*Technological*	*TNE_1*	*Internet of things (IoT)*
	RGE_2	*Extended producer responsibility*		*TNE_2*	*Artificial intelligence (AI) and machine learning (ML)*
	RGE_3	*Eco-design and standardization*		*TNE_3*	*Blockchain technology*
	RGE_4	*Carbon caps and emission trading*		*TNE_4*	*3D printing and additive manufacturing*
	RGE_5	*Monitoring and reporting requirements*		*TNE_5*	*Robotics and automation*
Financial	*FNE_1*	*Cost reduction of green manufacturing and services*	*Organizational*	*OGE_1*	*Top management commitment*
	FNE_2	*Increased profitability of green manufacturing and services*		*OGE_2*	*Employee training and education*
	FNE_3	*Green financing for loans, credit, or other financial instruments*		*OGE_3*	*Organizational structure*
	FNE_4	*Greater return on investment on green investments*		*OGE_4*	*Organizational culture*
	FNE_5	*Financial incentives for green practices*		*OGE_5*	*Strategic partnership*
Socio-cultural	*SCE_1*	*Heightened awareness and education*	*Infrastructural*	*IFE_1*	*Waste management facilities*
	SCE_2	*Corporate social responsibility*		*IFE_2*	*Industrial symbiosis*
	SCE_3	*Social norms and values*		*IFE_3*	*Logistics and transportation networks*
	SCE_4	*Community engagement and participation*		*IFE_4*	*Technological infrastructure*
	SCE_5	*Open training and education opportunities*		*IFE_5*	*Renewable energy infrastructure*
Environmental	*ENE_1*	*Concern over CO_2 emission*	*Geopolitical*	*GPE_1*	*Strategic regulations (such as IRA or CRMA)*
	ENE_2	*Concern over resource consumption*		*GPE_2*	*Global trend to minimize environmental impacts*
	ENE_3	*Concern over climate change*		*GPE_3*	*International agreements*
	ENE_4	*Concern over waste management*		*GPE_4*	*Geopolitical stability*
	ENE_5	*Concern over ecosystem*		*GPE_5*	*Supply chain risks*

*Notes: (1) *Reputable journals include English-speaking journals within Q2, (2) selected 5 items for each category based of frequency.*

Fuzzy Delphi and pilot testing

Fuzzy Delphi process

Step 1 (completed)	Step 2 (in progress)	Step 3 (pilot tested)	Step 4 (pilot tested)



Linguistic variables	Fuzzy number
Extremely low	(0.0, 0.0, 0.1)
Low	(0.0, 0.1, 0.3)
Medium low	(0.1, 0.3, 0.5)
Medium	(0.3, 0.5, 0.7)
Medium high	(0.5, 0.7, 0.9)
High	(0.7, 0.9, 1.0)
Extremely high	(0.9, 1.0, 1.0)

Expert panel (intended vs. pilot test)			Delphi interview ➡	Validity testing ➡	Defuzzification
Academia	Industry	Government			
(1) OOO (00 years experience) (2) OOO (00 years experience) (3) OOO (00 years experience) (4) OOO (00 years experience)	(5) OOO (00 years experience) (6) OOO (00 years experience) (7) OOO (00 years experience) (8) OOO (00 years experience)	(9) OOO (00 years experience) (10) OOO (00 years experience) (11) OOO (00 years experience) (12) OOO (00 years experience)	1) Email exchange 2) Face-to-face interaction 3) Narrative survey	1) Consistency of response 2) Kendall's W 3) Sensitivity analysis	1) Center of gravity method 2) Calculate fuzzy weights 3) Cut at 50% threshold
Energy engineering	Environmental engineering	Global climate environment			
(1) OOO (1 years experience) (2) OOO (1 years experience) (3) OOO (1 years experience) (4) OOO (0 years experience)	(5) OOO (2 years experience) (6) OOO (3 years experience) (7) OOO (2 years experience) (8) OOO (1 years experience)	(9) OOO (0 years experience) (10) OOO (5 years experience) (11) OOO (2 years experience) (12) OOO (1 years experience) (13) OOO (2 years experience)	Pilot test on HYU students	Sample bias detected	Proceeded regardless, to evaluate following procedures

Notes: (a, b, c), a=minimum weight, b=mean weight, c=maximum weight.

Analytical hierarchy process

Accepted enablers based on pilot test

Regulatory	Financial	Socio-cultural	Environmental	Technological	Organizational	Infrastructural	Geopolitical
RGE_1	FNE_1	SCE_1	ENE_1	TNE_1	OGE_1	IFE_1	GPE_1
(0.516, 0.725, 0.867)	(0.366, 0.566, 0.766)	(0.450, 0.650, 0.850)	(0.258, 0.458, 0.658)	(0.625, 0.825, 0.950)	(0.400, 0.600, 0.800)	(0.328, 0.512, 0.742)	(0.575, 0.775, 0.975)
RGE_2	FNE_2	SCE_2	ENE_2	TNE_2	OGE_2	IFE_2	GPE_2
(0.467, 0.675, 0.842)	(0.175, 0.325, 0.475)	(0.508, 0.708, 0.908)	(0.267, 0.467, 0.667)	(0.700, 0.900, 1.000)	(0.183, 0.367, 0.550)	(0.407, 0.579, 0.822)	(0.575, 0.775, 0.975)
RGE_3	FNE_3	SCE_3	ENE_3	TNE_3	OGE_3	IFE_3	GPE_3
(0.557, 0.757, 0.883)	(0.267, 0.467, 0.667)	(0.292, 0.492, 0.692)	(0.258, 0.458, 0.658)	(0.767, 0.967, 1.000)	(0.208, 0.375, 0.550)	(0.471, 0.651, 0.881)	(0.533, 0.717, 0.917)
RGE_4	FNE_4	SCE_4	ENE_4	TNE_4	OGE_4	IFE_4	GPE_4
(0.333, 0.533, 0.733)	(0.250, 0.450, 0.650)	(0.175, 0.375, 0.575)	(0.267, 0.467, 0.667)	(0.642, 0.857, 0.971)	(0.400, 0.575, 0.775)	(0.483, 0.679, 0.898)	(0.447, 0.617, 0.783)
RGE_5	FNE_5	SCE_5	ENE_5	TNE_5	OGE_5	IFE_5	GPE_5
(0.308, 0.508, 0.708)	(0.258, 0.458, 0.658)	(0.158, 0.358, 0.558)	(0.183, 0.383, 0.583)	(0.733, 0.921, 1.000)	(0.116, 0.276, 0.464)	(0.400, 0.600, 0.800)	(0.217, 0.366, 0.525

(1) Threshold: (0.217, 0.366, 0.525), (2) Accepted enablers: (3) Interquartile range: 0.284

Energy engineering	Resource engineering	Global climate environment
(1) OOO (1 years experience)	(5) OOO (2 years experience)	(9) OOO (0 years experience)
(2) OOO (1 years experience)	(6) OOO (3 years experience)	(10) OOO (5 years experience)
(3) OOO (1 years experience)	(7) OOO (2 years experience)	(11) OOO (2 years experience)
(4) OOO (0 years experience)	(8) OOO (1 years experience)	(12) OOO (1 years experience)
		(13) OOO (2 years experience)

Survey design for AHP

"How important is the enabler at a scale from 1 to 9"

Not important at all — *Extremely important*

1 ● ● ● ● ● ● ● ● ● 9

"How important is category A compared to category B at a scale from 1 to 9"

Same importance — *Far more important*

1 ● ● ● ● ● ● ● ● ● 9

Pairwise comparison matrix (comparative and relative weights)

	Regulatory	Financial	Socio-cultural	Environmental	Technological	Organizational	Infrastructural	Geopolitical
Pairwise comparison matrix								
Regulatory	***1***	*3*	*6*	*4*	*2*	*7*	*3*	*3*
Financial	*1/3*	***1***	*4*	*1/2*	*2*	*1/4*	*1*	*2*
Socio-cultural	*1/6*	*1/4*	***1***	*1/2*	*1/4*	*1/2*	*1/5*	*1/6*
Environmental	*1/4*	*2*	*2*	***1***	*1/3*	*2*	*1*	*1/2*
Technological	*1/2*	*1/2*	*4*	*3*	***1***	*3*	*2*	*2*
Organizational	*1/7*	*4*	*2*	*1/2*	*1/3*	***1***	*1/2*	*1/3*
Infrastructural	*1/3*	*1*	*5*	*1*	*1/2*	*2*	***1***	*1/2*
Geopolitical	*1/3*	*1/2*	*6*	*2*	*1/2*	*3*	*2*	***1***
Relative weights								
Regulatory	***1.000***	*2.623*	*10.039*	*3.309*	*1.903*	*3.335*	*3.208*	*2.365*
Financial	*0.381*	***1.000***	*3.828*	*1.262*	*0.725*	*1.271*	*1.223*	*0.902*
Socio-cultural	*0.100*	*0.261*	***1.000***	*0.330*	*0.190*	*0.332*	*0.320*	*0.236*
Environmental	*0.302*	*0.793*	*3.034*	***1.000***	*0.575*	*1.008*	*0.969*	*0.715*
Technological	*0.526*	*1.378*	*5.276*	*1.739*	***1.000***	*1.753*	*1.686*	*1.243*
Organizational	*0.300*	*0.786*	*3.010*	*0.992*	*0.571*	***1.000***	*0.962*	*0.709*
Infrastructural	*0.312*	*0.818*	*3.129*	*1.031*	*0.593*	*1.040*	***1.000***	*0.737*
Geopolitical	*0.423*	*1.109*	*4.245*	*1.399*	*0.805*	*1.410*	*1.357*	***1.000***
Aggregated	***0.299***	***0.114***	***0.030***	***0.090***	***0.157***	***0.090***	***0.093***	***0.127***

Saaty (2000)	*N*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
	RCI	*0.00*	*0.00*	*0.58*	*0.90*	*1.12*	*1.14*	*1.35*	*1.41*	*1.45*	*1.49*

Notes: Maximum Eigenvalue (λ_max)=9.305, consistency index=0.186, consistency ratio=0.132

Summary of analytical results

Category rank	Relative weight (category)	Accepted item no.	Item	Item description	Relative weight (item)	Item rank
RGE	0.299	2	RGE_2	Extended producer responsibility	0.342	1
			RGE_3	Eco-design and standardization	0.310	3
TNE	0.157	5	TNE_1	Internet of things (IoT)	0.294	4
			TNE_2	Artificial intelligence (AI) and machine learning (ML)	0.326	2
			TNE_3	Blockchain technology	0.245	7
			TNE_4	3D printing and additive manufacturing	0.181	11
			TNE_5	Robotics and automation	0.229	8
GPE	0.127	2	GPE_1	Strategic regulations (such as IRA or CRMA)	0.278	5
			GPE_2	Global trend to minimize environmental impacts	0.149	13
FNE	0.114	2	FNE_1	Cost reduction of green manufacturing and services	0.197	10
			FNE_3	Green financing for loans, credit, or other financial instruments	0.213	9
IFE	0.093	5	IFE_1	Waste management facilities	0.262	6
			IFE_2	Industrial symbiosis	0.165	12
			IFE_3	Logistics and transportation networks	0.133	14
			IFE_4	Technological infrastructure	0.068	18
			IFE_5	Renewable energy infrastructure	0.036	20
ENE	0.091	2	ENE_2	Concern over resource consumption	0.117	15
			ENE_4	Concern over waste management	0.094	17
OGE	0.090	1	OGE_1	Top management commitment	0.101	16
SCE	0.030	2	SCE_1	Heightened awareness and education	0.052	19
			SCE_2	Corporate social responsibility	0.020	21

Implications and limitations of pilot test

Implications

- *The most significant driver for CE transition are regulatory and institutional forces that mandate people, organizations, and systematic processes to engage in circular and sustainable practices.*
- *The second largest influencer is technological aspects, indicating that the transition of CE heavily relies on technological advances along with technological feasibility concerns that enable CE practice to integrate smoothly in daily operations.*
- *Geopolitical factors were found to be the fourth, implying that for countries like South Korea, the transition to CE is greatly influence by foreign policy mandates with consideration for the exports market.*
- *Financial enablers at a relative weight of 0.114 signifies that the costs and expenses associated with the transition can be significant barriers.*
- *Other aspects fall relatively short, weighing under the 0.1 threshold— downplaying environmental, social, infrastructural, and organizational enablers.*

Limitations

- *Our current experiment is likely to include a sampling bias as we have narrowed the focus to in-school respondents.*
- *Aspects such as technology may have been overemphasized due to most responses stemming from engineering backgrounds.*
- *Geopolitical enablers may also have been oversized due to GCE student biases.*
- *Contrastingly, aspects such as social awareness and organizational ideas may have been overlooked due to similar issues.*
- *Additionally, our study currently lacks sufficient measurement assessments to evaluate whether the data and samples do not suffer from consistency, validity, and accuracy issues.*

Future research direction

Current research

Common grounds

1. Comprehensive literature review and identify research gaps
2. Categorize preliminary enablers list based on LR

Pilot test

3. Pilot test: Fuzzy Delphi interview with HYU M.A. students
4. Sort key enablers based on defuzzified results
5. Conduct AHP questionnaire based on Delphi results
6. AHP survey to same group of students (Round 1)
7. Sort initial response, edit questionnaire and repeat (round 2)
8. Identify results and produce hierarchal ranking
9. Derive major implications and limitations based on study
10. Present research and receive feedback from field experts

Planned research

Actual test

3. Configure expert panel (academia, industry, government)
4. Fuzzy Delphi interview with expert panel
5. Sort key enablers based on finalized defuzzified results
6. Conduct AHP questionnaire based on Delphi results
7. AHP survey to same group of students (Round 1)
8. Sort initial response, edit questionnaire and repeat (round 2)
9. Difference analysis based on expert group (pairwise comparison)
10. Identify results and produce hierarchal ranking
11. Derive major implications and limitations based on new results
12. Build conclusion

Expected research schedule

Delphi stage: Dec. 02. 2023 ~ Dec. 10. 2023
AHP round (1): Dec. 13. 2023 ~ Dec. 20. 2023
AHP round (2): Dec. 22. 2023 ~ Dec. 29. 2023

Thank you
Q&A