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Thailand's Nuclear Energy System Assessment: KIND-ET and CENESO

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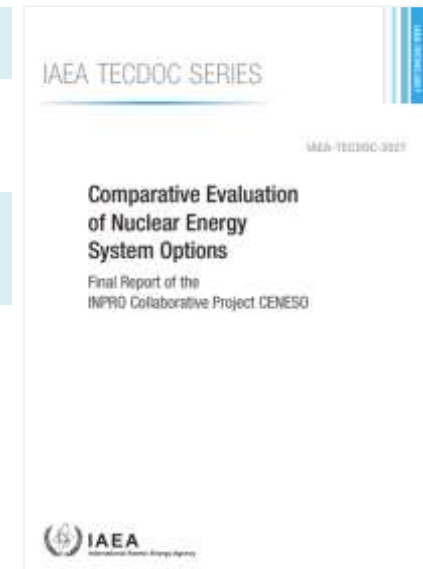
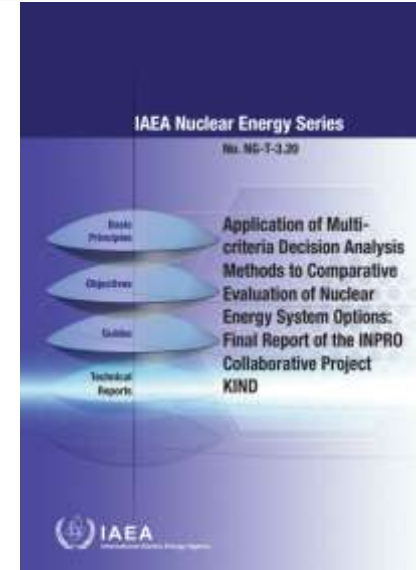
Introduction



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- KIND** and **CENESO** are **INPRO** collaborative projects developed to support the comparative evaluation of nuclear energy systems and non-nuclear options, to support long-term energy planning and decision-making.

	KIND	CENESO
Full name	Key Indicators for Innovative Nuclear Energy Systems	Comparative Evaluation of Nuclear Energy System Options
Main purpose	Develop methodology for comparing NES options	Extend and apply that methodology
Core concept	Key Indicators	Comparative evaluation of system/scenario options
Method	MCDA / MAVT	MCDA/MAVT + expanded analyses
Tool	KIND Evaluation Tool (KIND-ET) Excel-based	Extended KIND-ET and additional modules
Alternatives	Mainly nuclear systems/technologies	Nuclear, non-nuclear and integrated scenarios
Output	Scores, rankings, sensitivity to weights	Rankings plus broader scenario/decision analysis



Background

- Thailand participated in the INPRO Collaborative Projects "**KIND**", initiated in 2014, and "**CENESO**", initiated in 2017.
- Originally, the development of key indicators (KIs) in KIND project was aimed for the countries interested in the near term deployment of innovative nuclear energy systems.
- Some KIs may not be applicable to the newcomer country where nuclear power plant does not exist, and conventional energy and renewable energy system are widely used and familiarly operated.
- Therefore, we suggest the set of KIs which is designed for a comparative assessment of two or more energy systems: nuclear energy system (NES) & non-nuclear energy system (non-NES).

Framework of KIs development

- The development of KIs sets for newcomer country were considered based on the [INPRO assessment areas](#).

INPRO Assessment Areas	Main KIs areas	KIs for newcomer country
A – Economics	Yes	Yes
B – Infrastructures	No	Yes (Infra. / Public Acceptance)
C – Waste management	Yes	Yes (Public Acceptance)
D – Proliferation resistance	Yes	
E – Physical protection	No	
F – Environment	Yes	
G – Safety of nuclear reactors	Yes	Yes (Public Acceptance)
H – Safety of nuclear fuel cycle facilities	No	
No direct link to INPRO methodology	I – Maturity of innovative technology	

KIs for Nuclear Newcomers

The development of Key Indicators (KIs) for the assessment of nuclear energy options in newcomer countries.

High-level objectives	Areas titles	KI	Key Indicators
Cost	Economics	KI.1	LUEC
		KI.2	Cash flow
	National security	KI.3	Degree of dependence on supplier(s)
Acceptability	Public acceptance	KI.4	Survey of public acceptance
		KI.5	External cost
		KI.6	Risks to the public
	Infrastructure	KI.7	Status of legal framework
		KI.8	Status of state organizations
		KI.9	Availability of infrastructure to support owner/operator
		KI.10	Government policy
		KI.11	Availability of human resources

KIs for nuclear newcomers

- **Area of Economics: LUEC and Cash flow**

“Energy and related products and services from (nuclear) energy system shall be affordable and available”

KI. 1 - LUEC : Nuclear Economics Support Tool (NEST)

KI. 2- Cash flow: Investment limit , IRR and ROI.

- **Area of National security: Degree of dependence on supplier(s)**

“The way to strengthen national security is to maximize the degree of localization”

Degree of localization

- Technology
- Construction
- Fuel supply
- Operation
- Maintenance
- Waste management
- Decommissioning

KIs for nuclear newcomers

- **Area of Public acceptance: Survey of public acceptance, External cost, and Risk of accident**

KI.4 - Survey of public acceptance: Using data, which taken from a number of research and questionnaires, compilation reflecting public attitudes.

KI.5 - External cost: Using basic principle of waste management area of the INPRO methodology as basis, the approach is generalized to include the impacts of all effluents and emissions.

KI.6 - Risk of accidents: Accident rate, Fatalities rate, Maximum fatalities of a single accident, Accident cost rate, and Maximum accident cost of a single accident

KIs for nuclear newcomers

Area of Infrastructure

KI.7 - Status of legal framework

Lacks of legal frameworks in some areas will result in lower score

KI. 8 - Status of State Organizations

Independence and effective functions of regulatory authorities

KI.9 - Availability of infrastructure to support owner/operator

Level of adequacy on the existing capabilities of the domestic industries or government for providing related infrastructures

KI.10 - Government policy

Statement of government policy should clearly define

KI.11 - Availability of human resources

Sufficient and qualified of human resources to be utilized for an energy system

KIND-ET

**Apply KIND-ET for Thailand Case Study:
NES & non-NES**

Introduction

- Coal power is considered a potential energy source in Thailand as presented in PDP 2015.
- Coal technology has presently accounted for approximately 20% of total electricity production.
- Electricity Generating Authority of Thailand (EGAT) has planned to install a few more Coal Power Plants (CPPs) across the country in the near future.
- To comparative evaluation energy system scenarios between nuclear energy system (NES) & non-nuclear energy system which is coal power plant (CPP).

NES (NPP) → ABWR, AP1000, ATMEA1, VVER1200, ACPR1200, and APR1400

Non-NES → Coal-fired power plant (CPP) 600 MWe

**** All values are determined based on articles or reports published by national or international organizations, reports or presentations of EGAT, or expert judgments.**

Assumptions

Parameters	Nuclear	Coal-fired
Net electric power [MW]	1000 - 1400	600
Construction period [year]	4 - 6	3.5 - 4.5
Life time of plant [year]	60	40
Average load factor [-]	0.9	0.75
Decommissioning cost [mill/kWh]	0 - 0.14	0.03 - 0.12
Overnight cost [\$/kWe]	2577 - 4983	665 - 3002
Variable operation and maintenance cost [mill/kWh]	9.88 - 18.70	1.67 - 11.11
Fuel price [USD/GJ]		0.86 - 1.85
Real fuel price escalation rate (RFE)		0.01
Nuclear fuel backend cost [\$/kg]	379 - 2449	
Unloaded fuel average burnup [MWd/kg]	48.4 - 60	
Net thermal efficiency [%]	34 - 37	37.7
Reactor first core average power density [kW/kg]	25 - 40.2	
Natural U purchase cost [\$/SWU]	135	
U conversion cost [\$/SWU]	9	
U enrichment cost [\$/SWU]	146	
Nuclear fuel fabrication cost [\$/SWU]	312	

Scoring scale

High-level objectives titles	Areas titles	Indicators titles	Indicators abbr.	NES	CPP
Economics	Economics	Levelized unit electricity cost (LUEC)	KI. 1	၈၀	၈
		Cash flow	KI. 2	၈	၈၀
		Degree of dependence on supplier(s)	KI. 3	၈	၈
Acceptability	Public acceptance	Risks to the public	KI. 4	၈	၈
		Survey of public acceptance	KI. 5	၈	၈
		External cost	KI. 6	၈	၈၀
	Infrastructure	Status of legal framework	KI. 7	၈	၈၀
		Status of state organizations	KI. 8	၈	၈၀
		Availability of infrastructure to support owner/operator	KI. 9	၈	၈၀
		Government policy	KI. 10	၀	၈
		Availability of human resources	KI. 11	၈	၈

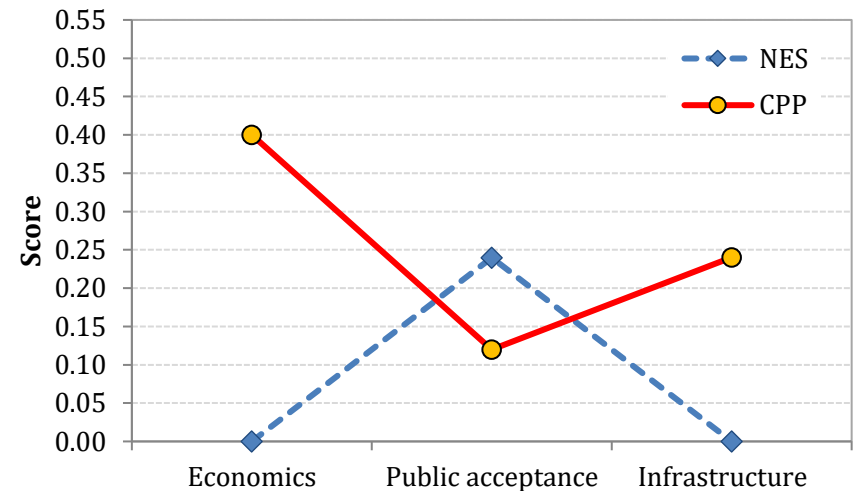
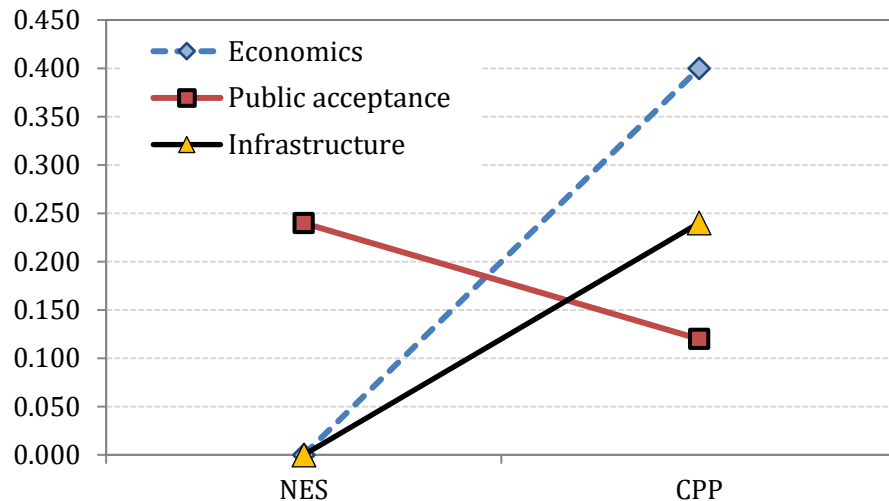
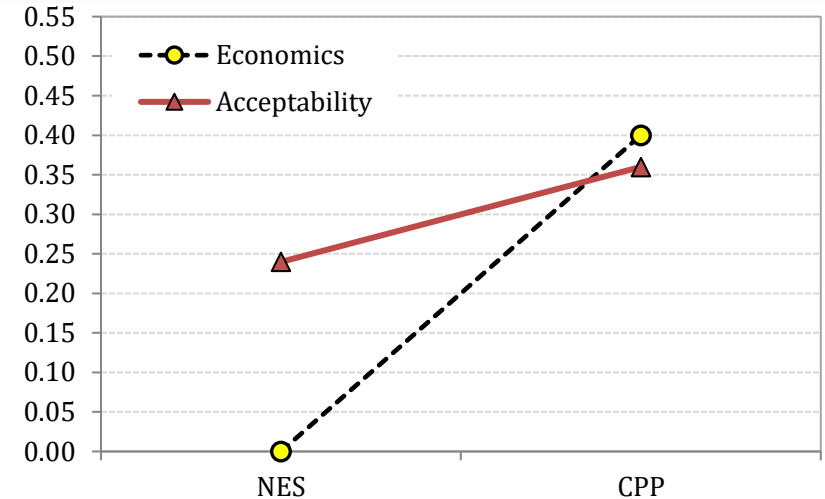
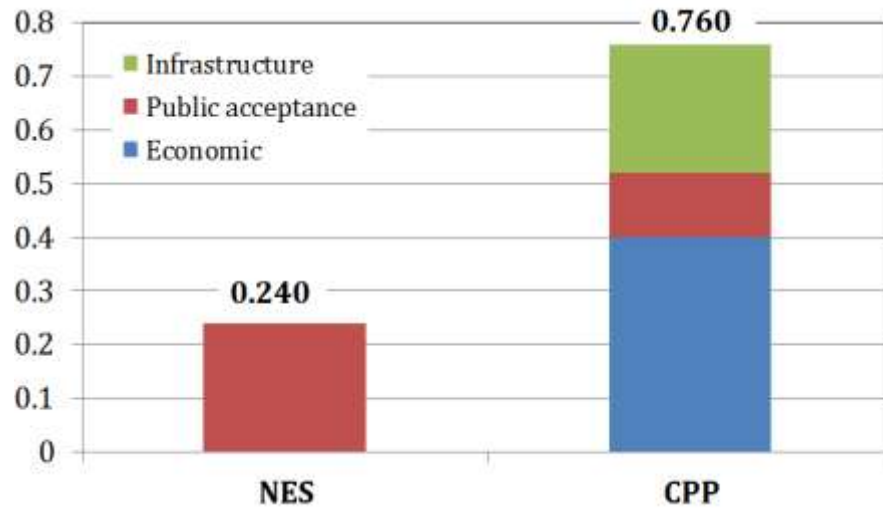
Weighting factors



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High-level objectives titles	High-level objectives weights	Areas titles	Areas weights	Indicators abbr.	Indicators weights	Final weights
Economics	0.4	Economics	1	KI. 1	0.4	0.16
		Economics		KI. 2	0.4	0.16
		Economics		KI. 3	0.2	0.08
Acceptability	0.6	Public acceptance	0.6	KI. 4	0.333	0.12
		Public acceptance		KI. 5	0.333	0.12
		Public acceptance		KI. 6	0.333	0.12
		Infrastructure	0.4	KI. 7	0.2	0.048
		Infrastructure		KI. 8	0.2	0.048
		Infrastructure		KI. 9	0.1	0.024
		Infrastructure		KI. 10	0.3	0.072
		Infrastructure		KI. 11	0.2	0.048

Results KIND-ET



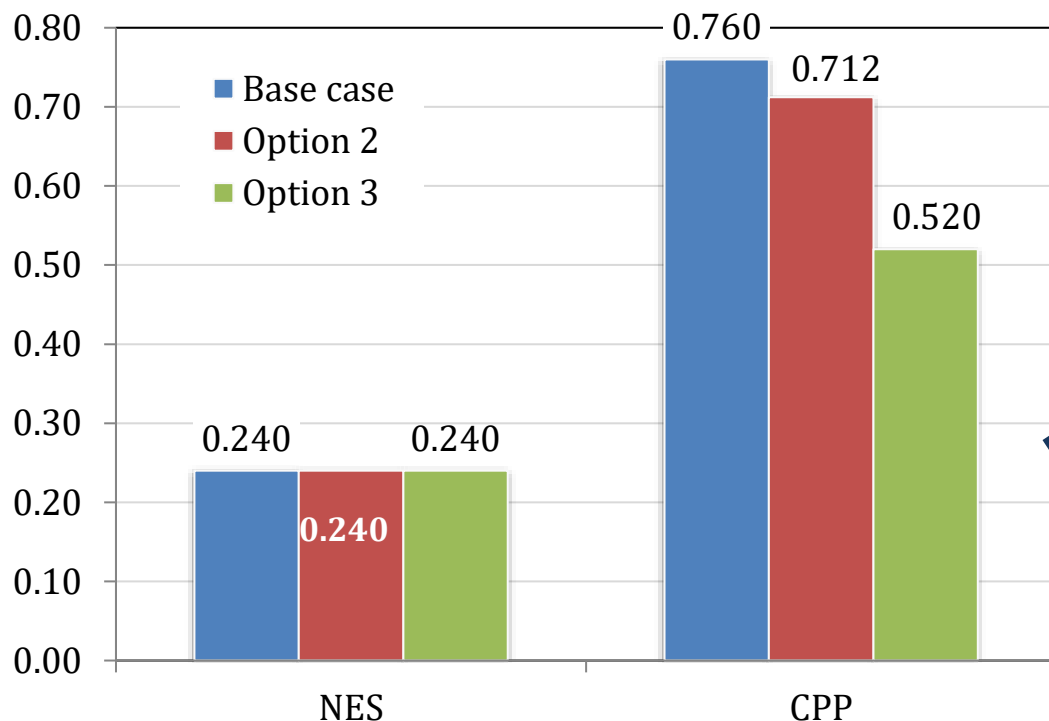
Weighting sensitivity analysis & Scenarios

Scenarios

- **Base case:** Within a 2-level objective tree with the weighting factor 0.4:0.6.
- **Option 1:** Acceptability (0.9) : Economics (0.1) and highly concerned in public acceptance (0.8) rather than the infrastructure (0.2).
- **Option 2:** In the **next 10 years**, the readiness of infrastructure for NES could be increased.
- **Option 3:** In the **next 20 years**, the readiness of infrastructure for NES could be same as CPP.

Areas titles	Indicators titles	Final weights			
		Base case	Option 1	Option 2	Option 3a
Economics	Levelized unit electricity cost (LUEC)	0.160	0.040	0.160	0.160
Economics	Cash flow	0.160	0.040	0.160	0.160
Economics	Degree of dependence on supplier(s)	0.080	0.020	0.080	0.080
Public acceptance	Risks to the public	0.120	0.240	0.120	0.120
Public acceptance	Survey of public acceptance	0.120	0.240	0.120	0.120
Public acceptance	External cost	0.120	0.240	0.120	0.120
Infrastructure	Status of legal framework	0.048	0.036	0.048	0.048
Infrastructure	Status of state organizations	0.048	0.036	0.048	0.048
Infrastructure	Availability of infrastructure to support owner/operator	0.024	0.018	0.024	0.024
Infrastructure	Government policy	0.072	0.054	0.072	0.072
Infrastructure	Availability of human resources	0.048	0.036	0.048	0.048

Results & Conclusions (KIND-ET)



Base case

Levels	NES	CPP
Multi-attribute value function	0.240	0.760
High-level objectives scores		
Economics	0.000	0.400
Acceptability	0.240	0.360
Areas scores		
Economics	0.000	0.400
Public acceptance	0.240	0.120
Infrastructure	0.000	0.240

Option 3

Levels	NES	CPP
Multi-attribute value function	0.240	0.520
High-level objectives scores		
Economics	0.000	0.400
Acceptability	0.240	0.120
Areas scores		
Economics	0.000	0.400
Public acceptance	0.240	0.120
Infrastructure	0.000	0.000

- The readiness of NES's infrastructure has not effect on the score of NES, but it decreases the score of CPP.
- CPP has more attractive than NES, even the readiness of infrastructure of NES is the same.

CENESO

**THAILAND CASE STUDY ON
SENSIVITY/UNCERTAINTY ANALYSIS WITH
RESPECT TO THE NATIONAL CASE STUDY**

Assumptions

- The background of Thailand's power generation, about **65% of the whole power generation depended on natural gas power plant and 20% depended on coal power plant.**

The fuel requirements for Thailand **PDP 2015**

Fuel	2014	2026	2036
Imported hydropower	7%	10-15 %	15-20 %
Clean coal including lignite	20%	20-25 %	20-25 %
Renewable energy	8%	10-20 %	15-20 %
Natural gas	64%	45-50 %	30-40 %
Nuclear	-	-	0-5 %
Diesel / Fuel oil	1%	-	-

NES (NPP)

→ ABWR, AP1000, ACPR1200, ATMEA1 and VVER1200

Non-NES

→ Coal-fired power plant (CPP)

→ Integrated gasification combined cycle (IGCC) 600 MW_e

→ Natural gas power plant (NGPP)

Two scenarios:

- The 0th year case:** the construction of a new power generation plant is assumed to start in a few years
- The 20th year case:** the construction of a new power generation started in the next 20 years

Weighting factors & Scoring scale

Scoring scale

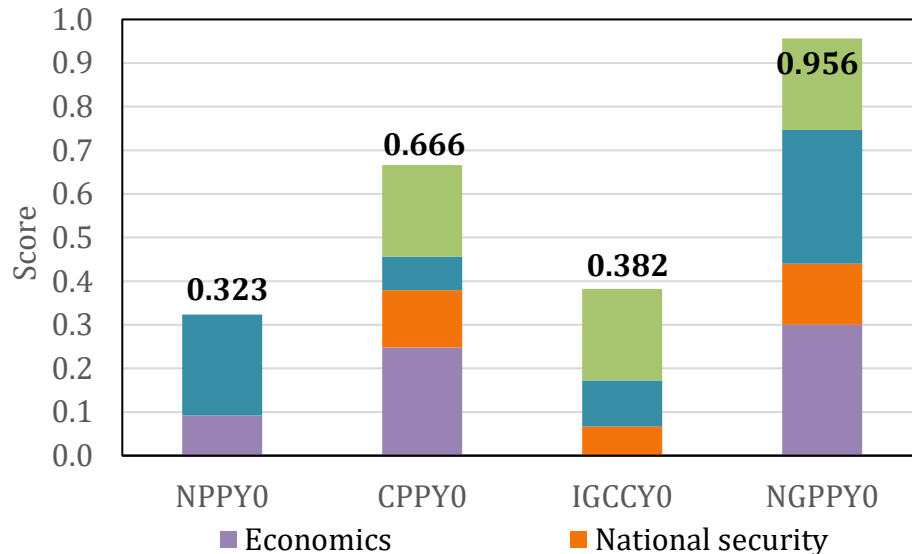
Areas	Key indicator	Goal	The 0 th year				The 20 th year			
			NES	CPP	IGCC	NGPP	NES	CPP	IGCC	NGPP
Economics	LUEC	min	96	81	118	77	81	100	118	101
	Cash flow	max	0.8	7.5	0.0	10.0	10.0	6.5	5.0	8.1
National security	DDS	min	9	4.45	6.7	4.15	9	4.15	4.65	4.8
Public acceptance	Survey of public acceptance	max	2	6	6	8	2	6	8	10
	External cost	min	4.4	74.5	57	14.7	4.4	74.5	57	14.7
	Risks to the public	min	6	8	8	6.4	6	8	8	6.4
Infrastructure	Status of legal framework	max	4	10	10	10	10	10	10	10
	Status of state organizations	max	4	10	10	10	10	10	10	10
	Ava. of infra. to support owner/operator	max	4	7	7	7	10	10	10	10
	Government policy	max	2	7	7	7	10	10	10	10
	Availability of human resources	max	3.33	8	8	8	10	10	10	10

Weighting factors

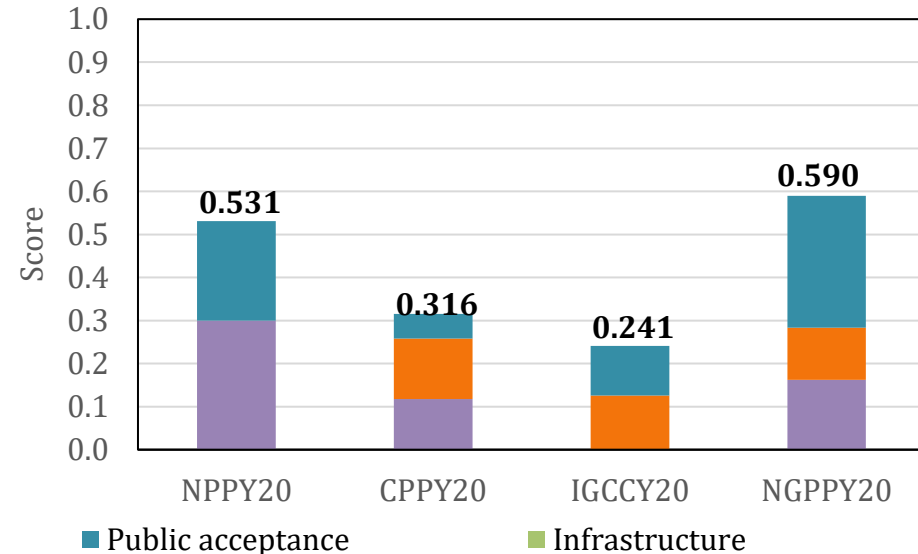
HLO titles	HLO weights	Areas titles	Areas weights	Indicators abbr.	Indicators weights	Final weights
Cost	0.3	Economics	1	KI. 1	0.5	0.150
				KI. 2	0.5	0.150
Acceptability	0.7	National security	0.2	KI. 3	1	0.140
		Public acceptance	0.5	KI. 4	0.333	0.117
				KI. 5	0.333	0.117
				KI. 6	0.333	0.117
		Infrastructure	0.3	KI. 7	0.2	0.042
				KI. 8	0.2	0.042
				KI. 9	0.1	0.021
				KI. 10	0.3	0.063
				KI. 11	0.2	0.042

Results & Conclusions (CENESO)

The 0th year case



The 20th year case



- **NGPP** is the **most attractiveness** because of the advantage on the cost, the acceptability and the readiness of infrastructure rather than the other energy systems.
- **CPP** has proven technology and long experience in Thailand, but **lower score in area of public acceptance** as compared with the NGPP.
- The attractiveness of **nuclear power plant** is significantly increased due to the development of time-dependent in infrastructure and more advantage in economic area.
- NGPP is still the ranks highest for the case of 20th year.

Final Remarks

- Thailand joined the INPRO KIND project to develop key indicators for nuclear newcomer countries and apply them in KIND-ET.
- KIND-ET supports comparison of nuclear and non-nuclear energy options using multi-attribute value theory.
- CENESO extends the approach to technology and scenario assessment for long-term energy planning.
- KIND-ET is the tool helps rank alternatives based on performance and decision-maker priorities.



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Thank you for your attention

Q & A

