The Study of Energy Vulnerability Indicators in Taiwan and Policy Implication: An Application of WEC Framework

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Contents

I. Introduction

- The energy supply situation in Taiwan is vulnerable. Taiwan's import energy dependence is higher than 97%. The ratio of import energy value over GDP was 12% in 2014. Both indicators are among the highest in the world.
- Taiwan is an island and hence the electricity grid is an isolated one. Furthermore, the energy policy of Taiwan under new government has shifted to nuclear-free homeland since May 20, 2016. Government plans to increase the renewable energy and gas-fired power plants to substitute nuclear and coal-fired power plants by 2025. It adds high uncertainty on Taiwan's energy future.

- This paper reviews various methods of measuring energy vulnerability, and constructs a comprehensive energy security framework for Taiwan by modifying World Energy Council (WEC) framework.
  1) We then compile the data from various public reports or database and calculate the vulnerability indicators in Taiwan during 1990 Q1 to 2017 Q2.
  2) According to the framework of WEC, we contruct the energy vulnerability (EV) indicator of Taiwan by three sub-indicators: vulnerability of primary energy supply (PEV), vulnerability of infrastructure (IV), and vulnerability of end-use energy consumption (EEV).

Power Facilities

Figure 1: The Power Plant Distribution and Power Supply Area of Taiwan

Table 1: Regional Electricity Balance of Taiwan in July 2016

Unit：GW

	Net Peaking Capability	Peak Load	Power Balance
Northern TW	13.33	13.91	-0.58
Central TW	13.25	10.77	2.48
Southern TW	12.79	11.04	1.75
Total	39.37	35.72	3.65

Sources: Taiwan Power Company.

Energy Policy of the Government

- Nuclear Free Homeland by 2025
- Energy mix target in 2025 :
  - Gas-fired 50%, Coal-fired 30%, Renewable Energy 20%

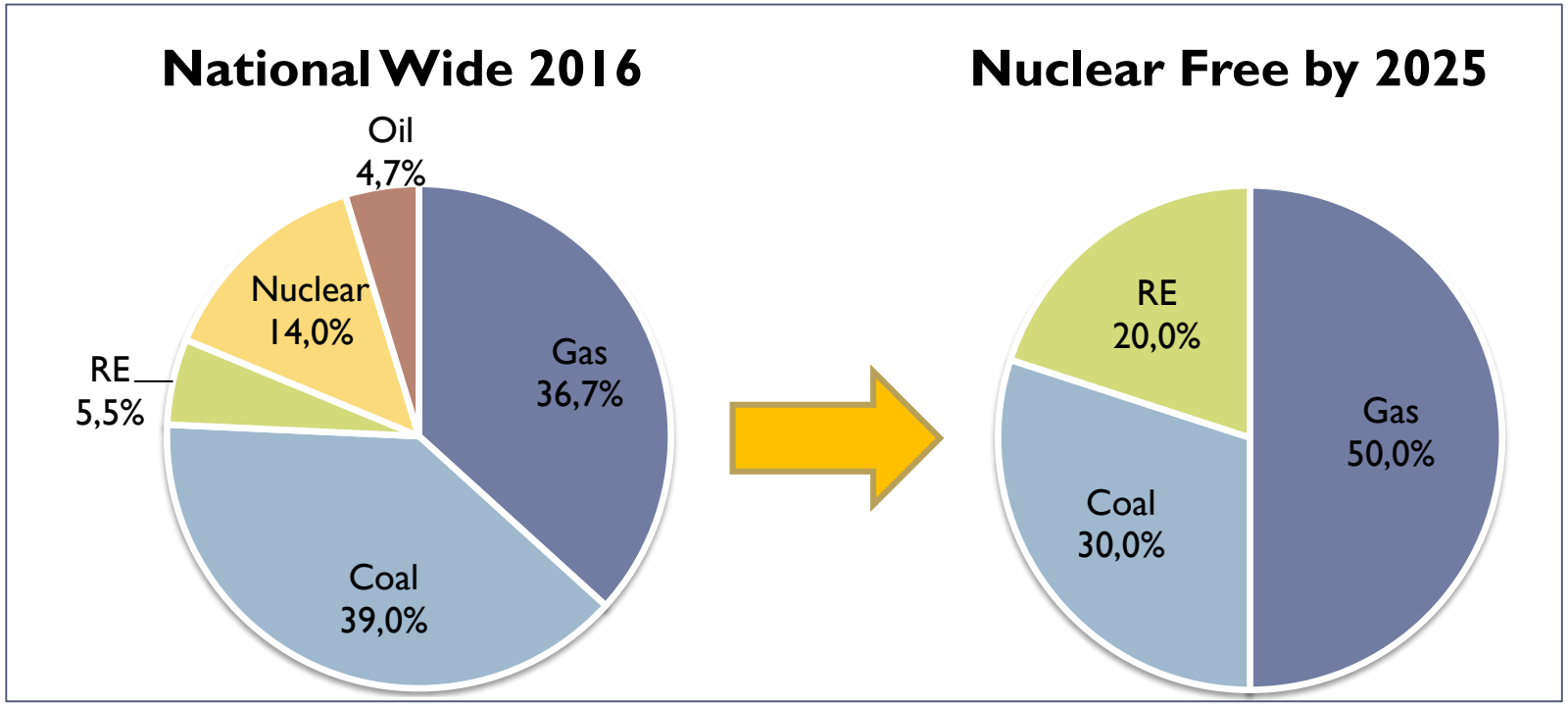


Figure 2: National Wide Electricity Allocation in Taiwan

II. Literature Review

2.1 U.S. Chamber of Commerce-International Energy Security Risk

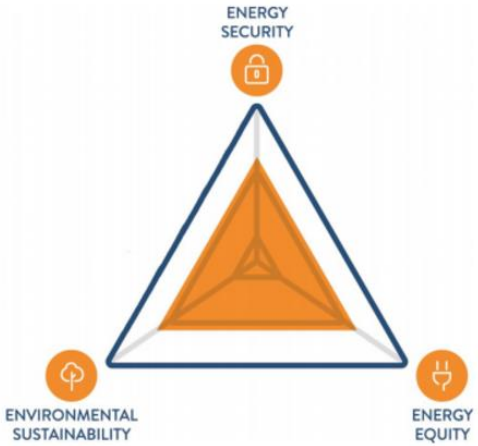
- U.S. Chamber of Commerce had constructed an index of International energy security risk to facilitate a better understanding of global energy markets.
- The index consists of eight sub-index as follows:

Sub-index	Global fuels	Fuel Imports	Energy Expendi-ture	Price & Market Volatility	Energy Use Intensity	Electric Power Sector	Transpor-tation Sector	Environ-mental Sector
Weight	15%	16%	19%	14%	15%	7%	8%	6%

- The index of international energy security risk mainly be used to analyze top 75 energy consumption countries in the world (include Taiwan).

2.2 WEC- Energy Trilemma Index

- WEC using the concept of balance score to show the performance in a country among trilemma, i.e., energy security, environmental sustainability and energy equity.
- The best country will achieve a score of AAA and the worst one will be DDD.



Sub-index	Energy Security	Energy Equity	Environmental Sustainability	Political Strength	Societal Strength	Economic Strength
Weight	25%	25%	25%	8.3%	8.3%	8.3%

- From the design of the weight, we can understand that the variation in energy and environment will lead to a significant impact on whole index.

2.3 WEF- Energy Architecture Performance Index (EAPI)

- EAPI review a country's energy security by economic growth & development, environmental sustainability and energy access & security and using equal weight to aggregate sub-indicators.
- The EPAI contains almost 140 countries in the world excluding Taiwan. However, EAPI doesn't publish the detailed compiled methodology so we can't conduct international comparisons with Taiwan.

2.4 WEC-Vulnerability Index

- World Energy Council (2010) and Frondel *et. al.*(2013) construct a clear system method to measure a country's energy vulnerability by three Sub-Indicators.
  1) The first sub-indicator is primary energy supply vulnerability.
  2) The second sub-indicator consider in particular the vulnerability and quality of the infrastructure for the electricity grid and natural gas.
  3) The third sub-indicator focus on the level of final energy consumption vulnerability in a country.
- Because the unit in sub-indicators were different, WEC apply the normalize method of min-max in order to make all sub-indicators consistent before aggregating.

III. Methodology of Energy Vulnerability Indicators and Data Sources

- The highlight of WEC framework is presented as Figure 3.

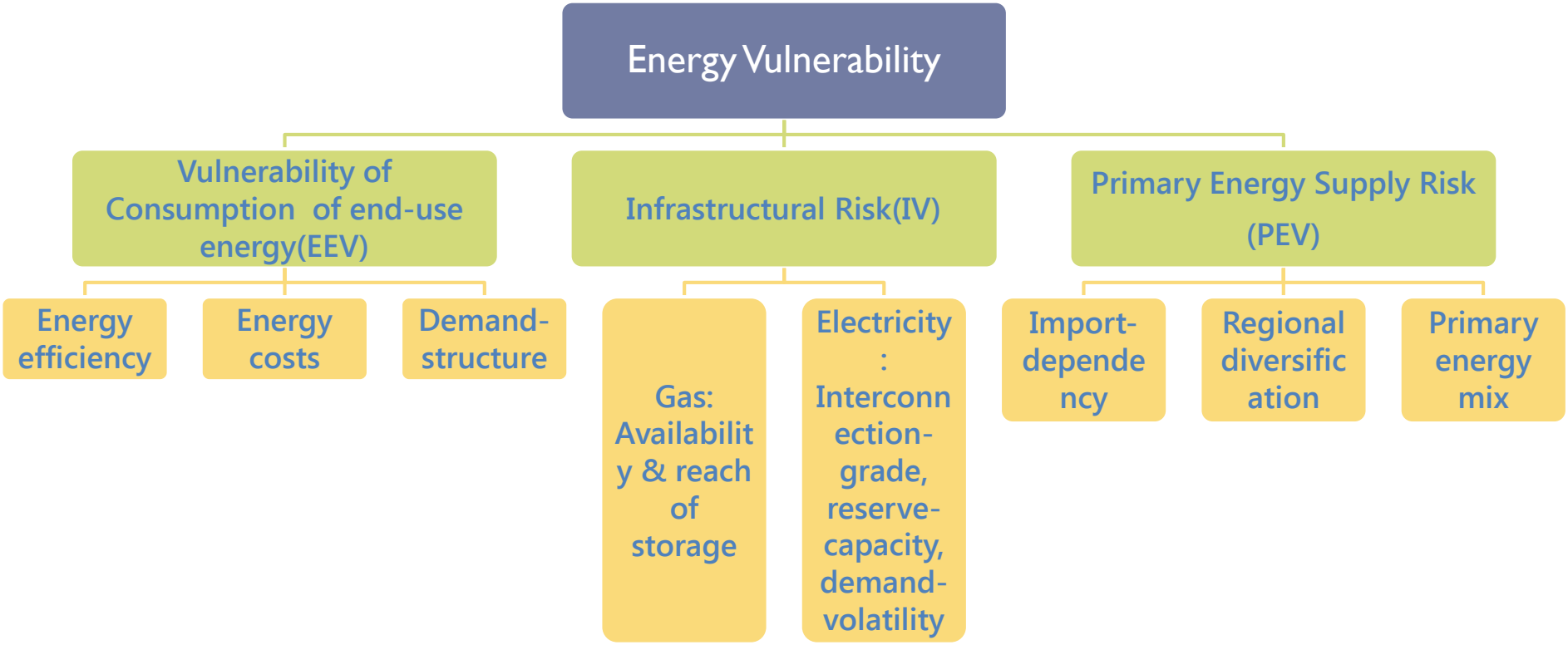


Figure 3: The Structure of Energy Vunlerability

3.1 Vulnerability of Primary Energy Supply (PEV)

- To measure a nation's entire vulnerability with respect to all kinds of fuel imports, we adopt the following equation:

$$PEV = w^T \cdot X^T \cdot R \cdot X \cdot w = w^T \cdot \Pi_J^T \cdot w \quad (1)$$

- According to Frondel *et. al*(2013), we denoting the risk probability of supply disruptions in export country j by rj, where 0 ≤ rj ≤ 1, and following quadratic form as a measure to capture a nation's supply risk related to fuel i:

$$PEV_i = x_i^T \cdot R \cdot x_i = x_{id}^2 \cdot r_d + \sum_{j=1}^{J} x_{ij}^2 \cdot r_j \quad (2)$$

3.2 Vulnerability of Infrastructure (IV)

- Turnover Rate of Nature Gas

$$= \frac{Max\ Quantaty\ Consumption\ of\ \ Nature\ Gas\ in\ a\ Season}{The\ Designed\ \ Capacity\ of\ \ Natural\ Gas} \quad (3)$$

- Electricity Mix

$$= \sum PEV_{it} \times \frac{Quantaty\ of\ \ Power\ Generation\ by\ Source\ i\ at\ time\ t}{Total\ \ Power\ Generation\ at\ time\ t}$$

$$i = Coal, oil, natural\ \ gas, nuclear, renewable...etc \quad (4)$$

- Deviation of Reserve Margin Ratio

$$= \lambda_1 \times \frac{|PRM_t - ORM|}{ORM} \times I(PRM_t > ORM) + \lambda_2 \times \frac{|PRM_t - ORM|}{ORM} \times I(PRM_t < ORM) \quad (5)$$

$$\lambda_1 = 0, \lambda_2 = 1$$

- Deviation of Operating Reserve Ratio

$$= \lambda_1 \times \frac{|POR_t - OOR|}{OOR} \times I(POR_t > OOR) + \lambda_2 \times \frac{|POR_t - OOR|}{OOR} \times I(POR_t < OOR) \quad (6)$$

$$\lambda_1 = 0, \lambda_2 = 1$$

3.2 Vulnerability of Infrastructure (IV)

- Deviation of Regional Electricity Demand

$$= \sum [(\lambda_1 \times \frac{|S_{it} - D_{it}|}{D_{it}} \times I(S_{it} > D_{it})) + (\lambda_2 \times \frac{|S_{it} - D_{it}|}{D_{it}} \times I(S_{it} < D_{it}))] \quad (7)$$

$$i = N, M, S, \lambda_1 = 0, \lambda_2 = 1$$

- Grid Interconnection with Other Countries

$$= \sum \left[\begin{array}{l} \lambda_1 \times \left| \frac{\textit{The Capacity of the Interconnections with Others Countries}}{\textit{Capacity of Native Country}} - \textit{Optimal Interconnections} \right| \\ \times I(\frac{\textit{The Capacity of the Interconnections with Others Countries}}{\textit{Capacity of Native Country}} > \textit{Optimal Interconnections}) \\ + \lambda_2 \times \left| \frac{\textit{The Capacity of the Interconnections with Others Countries}}{\textit{Capacity of Native Country}} - \textit{Optimal Interconnections} \right| \\ \times I(\frac{\textit{The Capacity of the Interconnections with Others Countries}}{\textit{Capacity of Native Country}} < \textit{Optimal Interconnections}) \end{array} \right]$$

$$\lambda_1 = 0, \lambda_2 = 1 \quad (8)$$

3.2 Vulnerability of Infrastructure (IV)

- Load Factor
  - Load factor is a ratio of average annual load to maximum annual load.
  - It provides information on how efficiently the power system equipment is used and, to a certain extent, helps understand how close the power supply system is to being overloaded.
  - When load factor is high, equipment usage efficiency is high and vice versa. At the same time, when load factor is close to 100%, the system might be at its capacity limit and could collapse with potential increase in peak demand.

3.3 Vulnerability of End-Use Energy Consumption (EEV)

- Final Energy Consumption Mix Risk

$$= \sum PEV_{it} / Infrastructure\ Vulnerability \times \frac{Quantity\ of\ Final\ Energy\ Consumption\ by\ Source\ i\ at\ time\ t}{Total\ Final\ Energy\ Consumption\ at\ time\ t} \quad (9)$$

$$i = coal, natural\ gas, electricity, renewable...etc$$

- Energy Intensity
  - The definition of energy intensity is final energy consumption per unit of real Gross Domestic Product (GDP).
  - This value shows energy efficiency of a nation's economy.
  - The lower the value is the higher the efficiency of energy use and hence energy users have higher ability to response energy prices, thereby reducing energy consumption vulnerability.
- Energy Price

$$\sum S_{it} \times P_{it} \quad (10)$$

$$i = coal, natural\ gas, electricity, renewable...etc$$

3.4 Normalization

- Because of the associated different indicators, which show specific facts at the individual levels of the system and therefore partly have different dimensions and value ranges, we adopt re-scale method that proposed by European Commission in order to consist the unit and value range in the interval of 0 and 1. The method of normalizing is min-max process:

$$I_{qt} = \begin{cases} (X_{qt} - Base)/(Top - Base), & if\ X_{qt} \le Top \\ 1, & if\ X_{qt} > Top \end{cases} \times 100 \qquad (11)$$

- Although we don't know the max value in each sub-indicator during analyzing time frame, the minimum risk or value will be zero and hence we set min be zero when we normalize each sub-indicator.

3.5 Time Span and Weighting

- Time Span:1990Q1~2017Q2
- Weighting for each sub-indicator:
  - According to the energy import share or structures
- The Calculation of EV
  - Choosing the maximum value of PEV, IV or EEV as the value of EV.

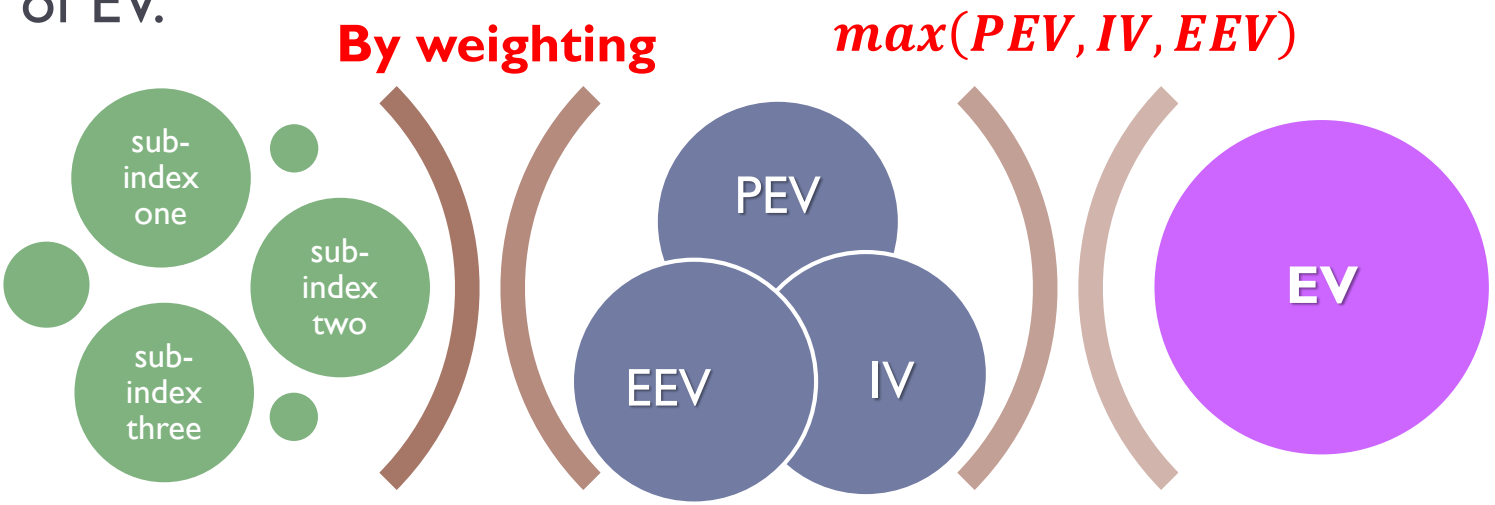
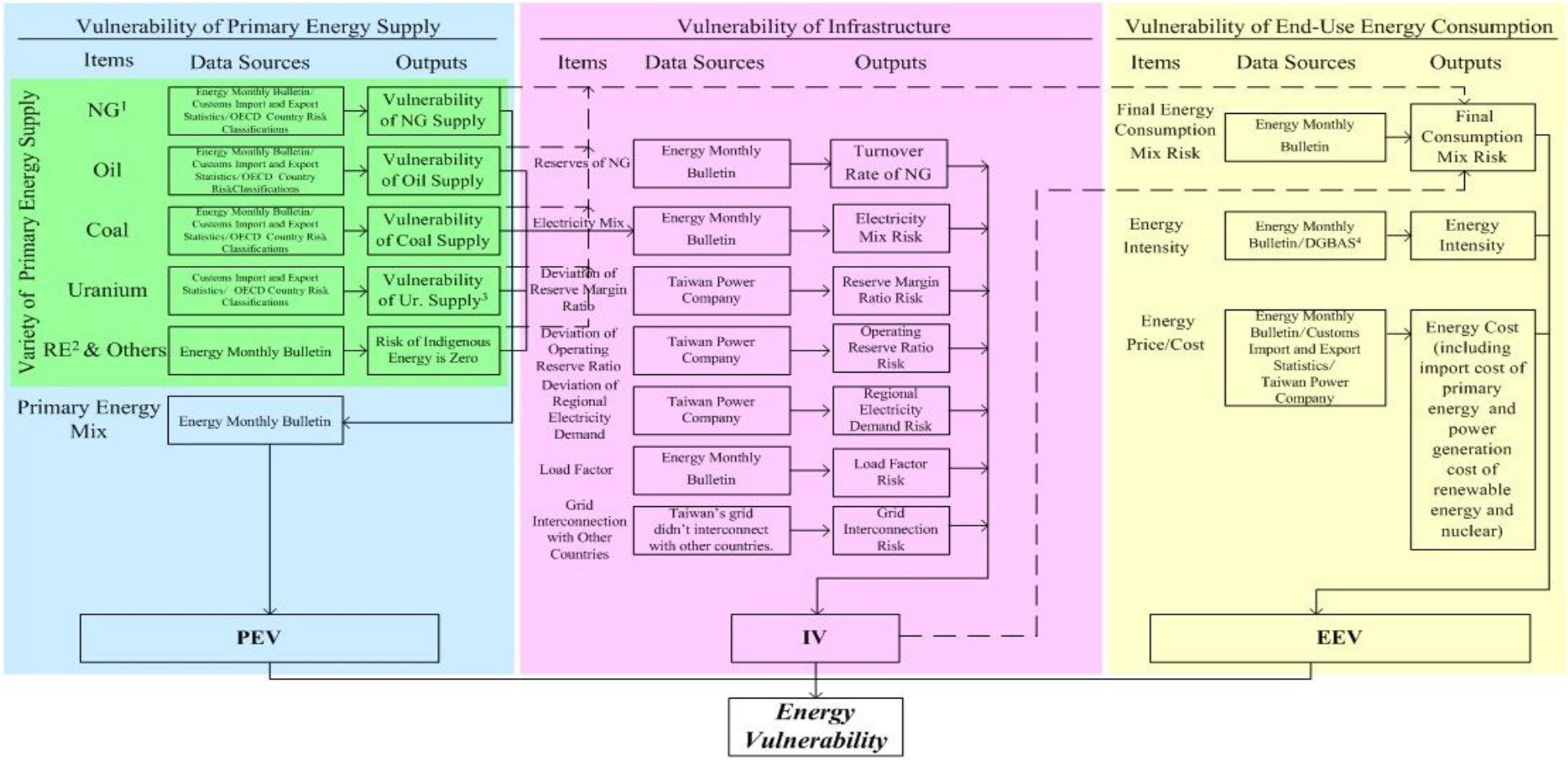


Figure 4: Diagram of Calculation of EV

Modified WEC Framework for Taiwan



[1] Nature Gas
[2] Renewable Energy
[3] Risk of Indigenous Energy is Zero
[4] Directorate-General of Budget, Accounting and Statistics (DGBAS), Executive Yuan, R.O.C. (Taiwan)

Figure 5: Framework of Vulnerability

IV. Results

4.1 Vulnerability of Primary Energy Supply (PEV)

- The oil product had the lion share of primary energy supply of Taiwan in 1990. The share of oil product was higher than 56% and nuclear was also higher than 16%.
- At the end of 2016, the share of LNG had increased and nuclear had decreased. Since 97 percent of energy supply relies on imports, we can understand that the PEV will be significantly affected by the risk of import LNG, oil and coal.

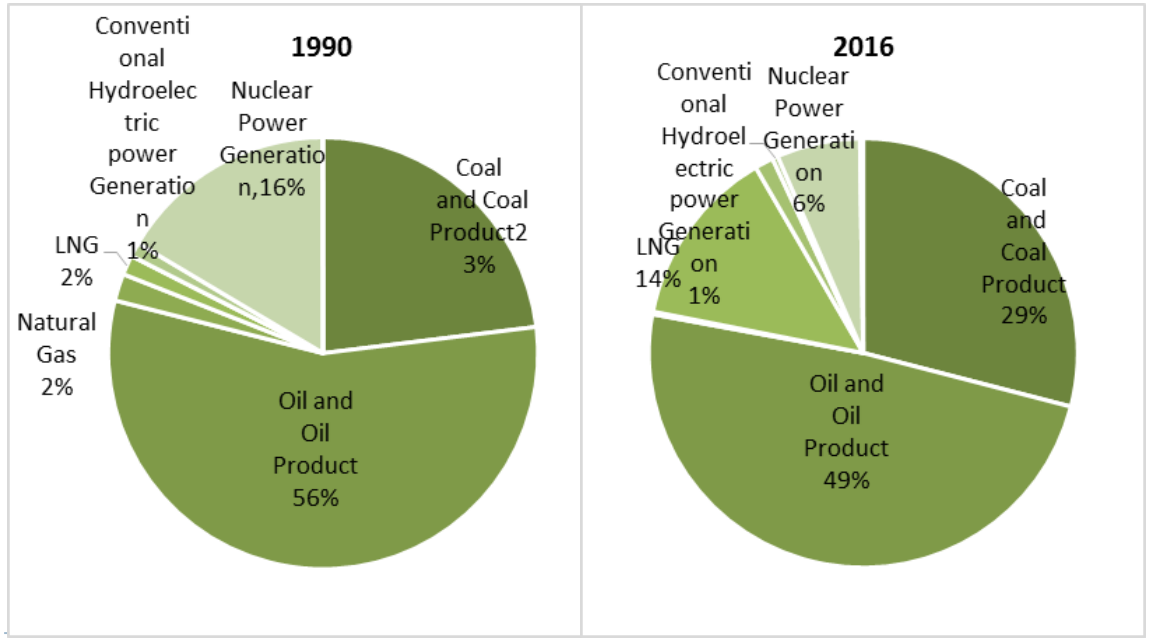


Figure 6: Primary Energy Structure of Taiwan on 1990 and 2016

4.1 Vulnerability of Primary Energy Supply (PEV)

- We found that the PEV_{coal}, PEV_{oil} and PEV_{NG} were decreasing after 2005.
- It could be contributable to that coal, oil and natural gas imported from lower political risk countries and import sources diversification.

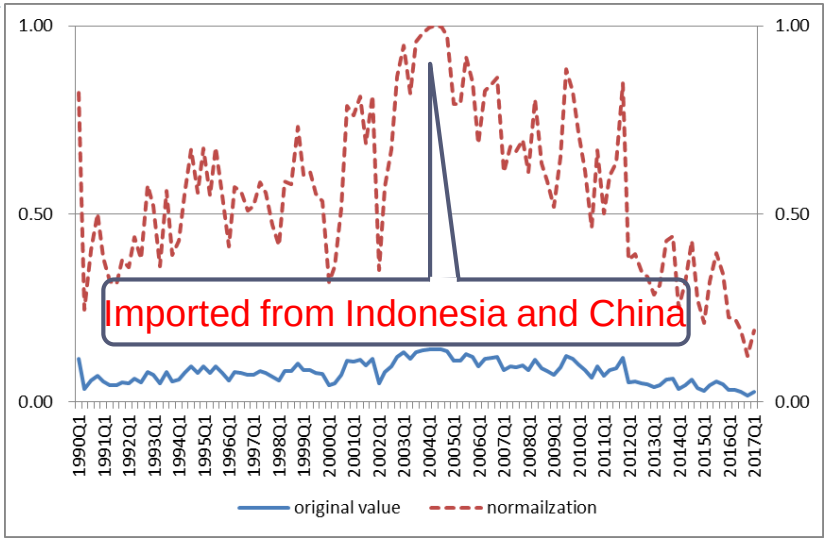


Figure 7: PEV_{coal} of Taiwan

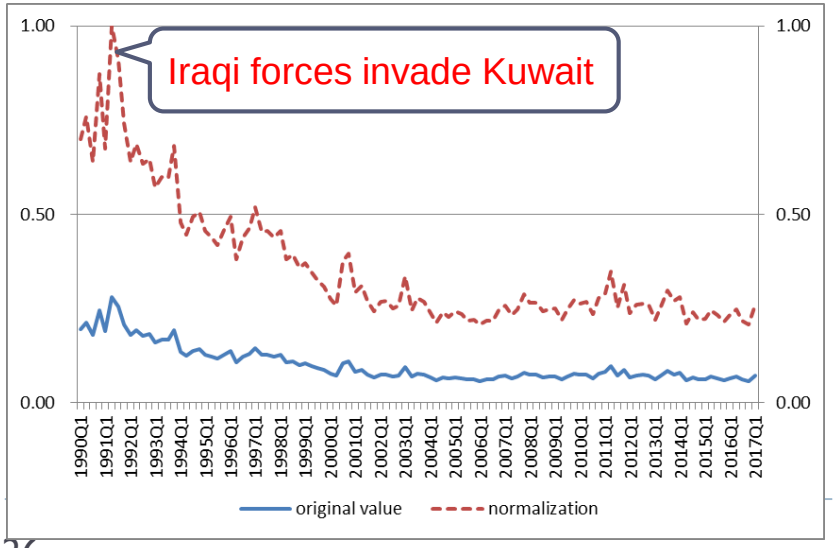


Figure 9: PEV_{oil} of Taiwan

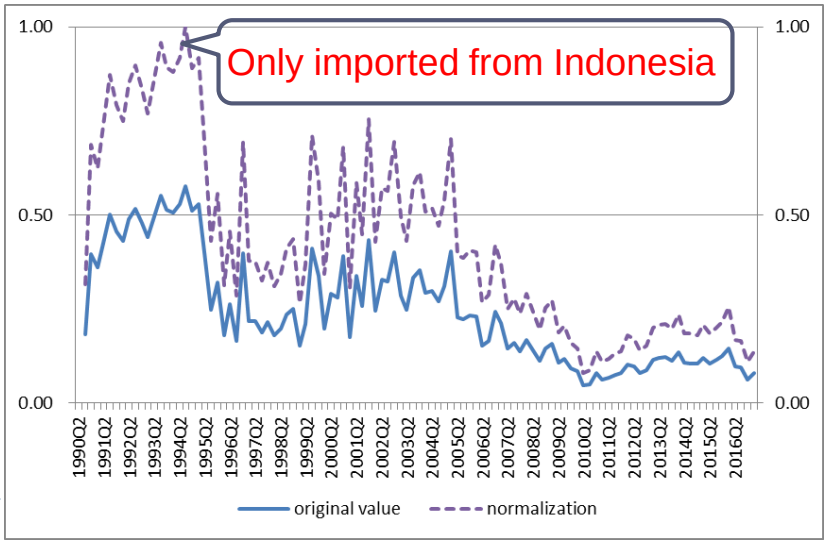


Figure 8: PEV_{NG} of Taiwan

4.1 Vulnerability of Primary Energy Supply (PEV)

- The value of PEV is reached the highest level in the end of1990.
- From the trend of PEV, it implies that the primary energy supply in Taiwan today is much safer than 26 years ago.

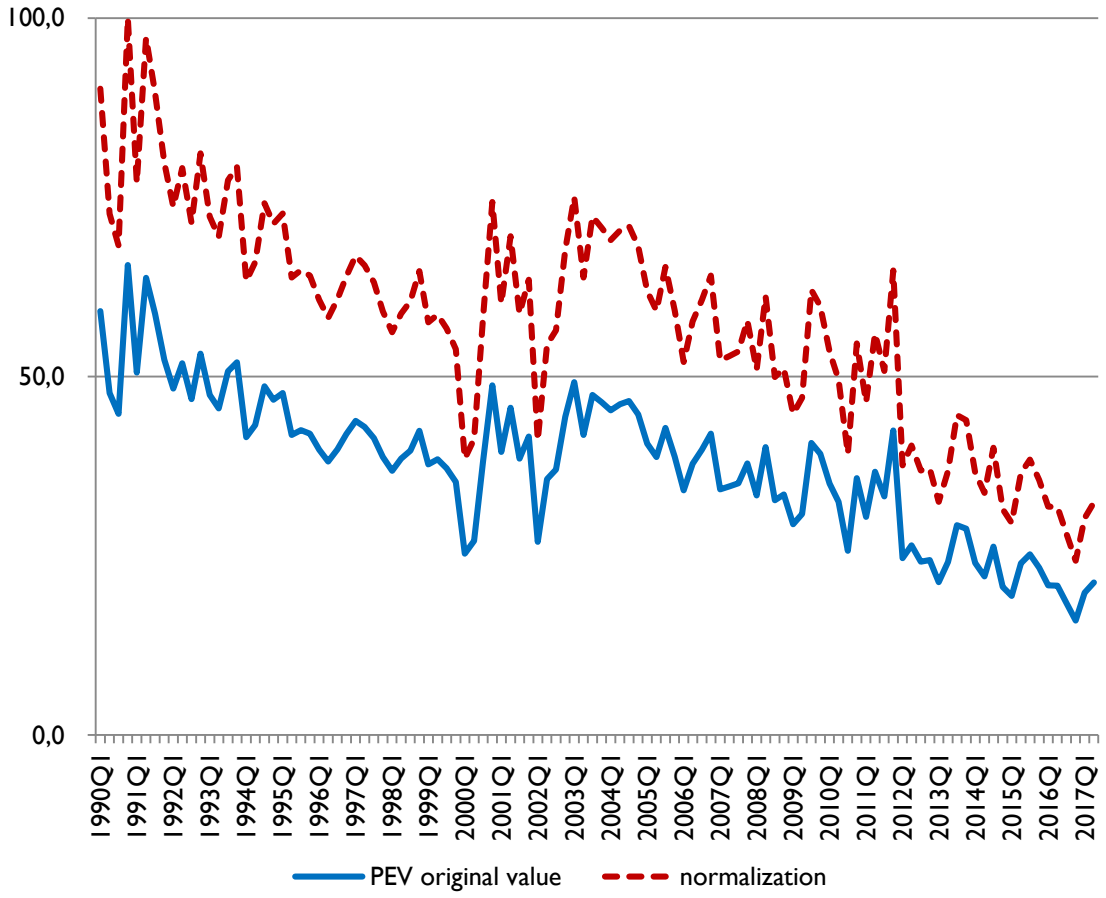


Figure 10: PEV of Taiwan

4.2 Vulnerability of Infrastructure (IV)

- The reserve margin ratio of electricity fell from 14.7 percent in 2014 to 10.4 percent in 2016.
- It's worth noting that he real operating reserve ratio was 5.5 percent in 2016 Q2, closed to the low reserve margin ratio of 5.36 percent on average during 1990-1996, in which electricity black-outs happened frequently.

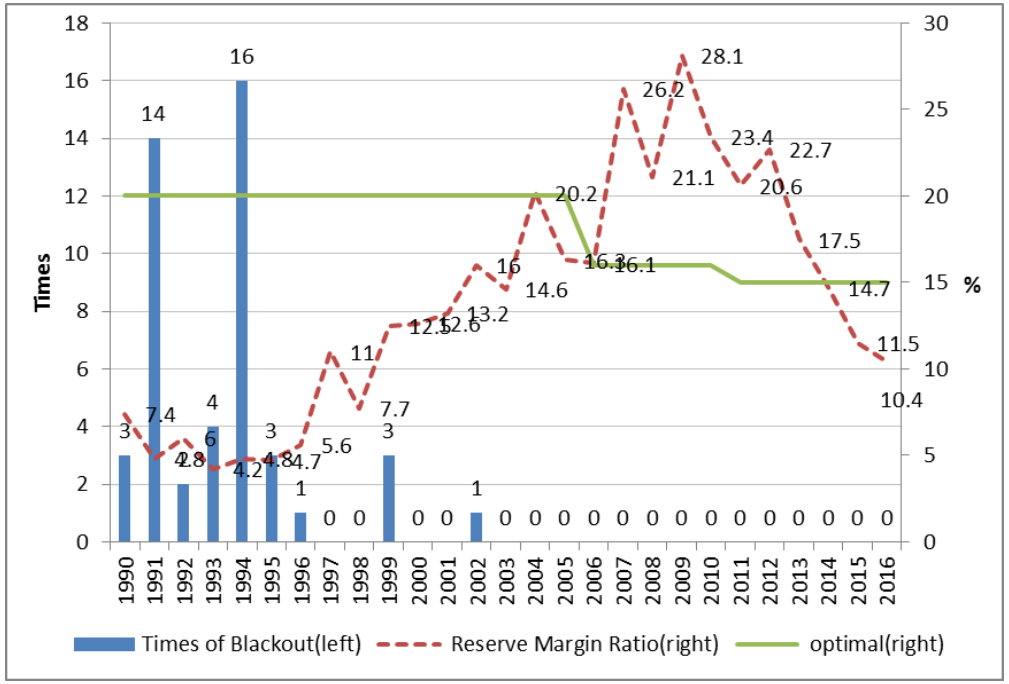


Figure 11: Times of Blackout and Reserve Margin Ratio of Taiwan

4.2 Vulnerability of Infrastructure (IV)

- In addition, the turnover rate of nature gas was increasing after 2008Q1 because of surging nature gas consumption and limited capacity.
- The value of turnover rate of natural gas was near the highest level during 2007 to 2008 in recent years.
- And hence this will push the energy security risk of infrastructure much higher.

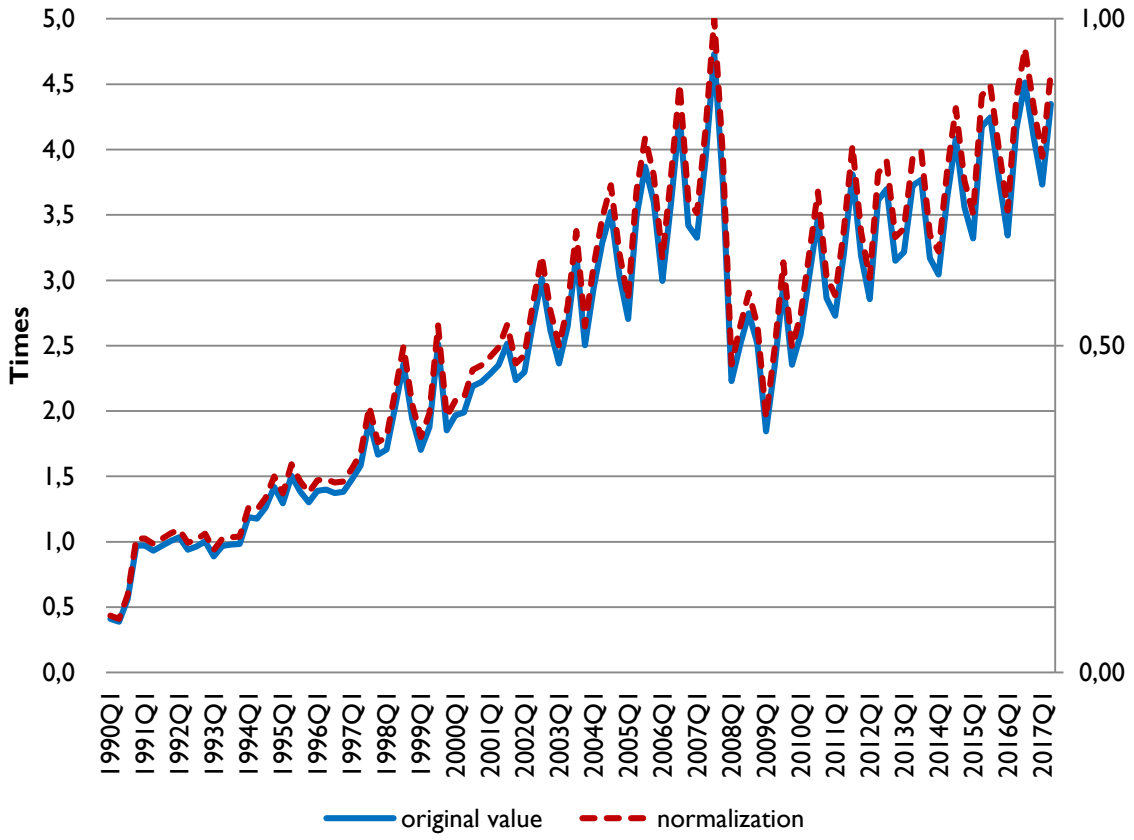


Figure 12: Turnover Rate of Natural Gas of Taiwan

4.2 Vulnerability of Infrastructure (IV)

- Taiwan faces higher infrastructure vulnerability than before for lack of power supply capacity, natural gas storage and regional excess electricity demand.
- Lack of power supply capacity is mainly resulted from Nuclear-Free Homeland Policy adopted by the government since May 20, 2016.

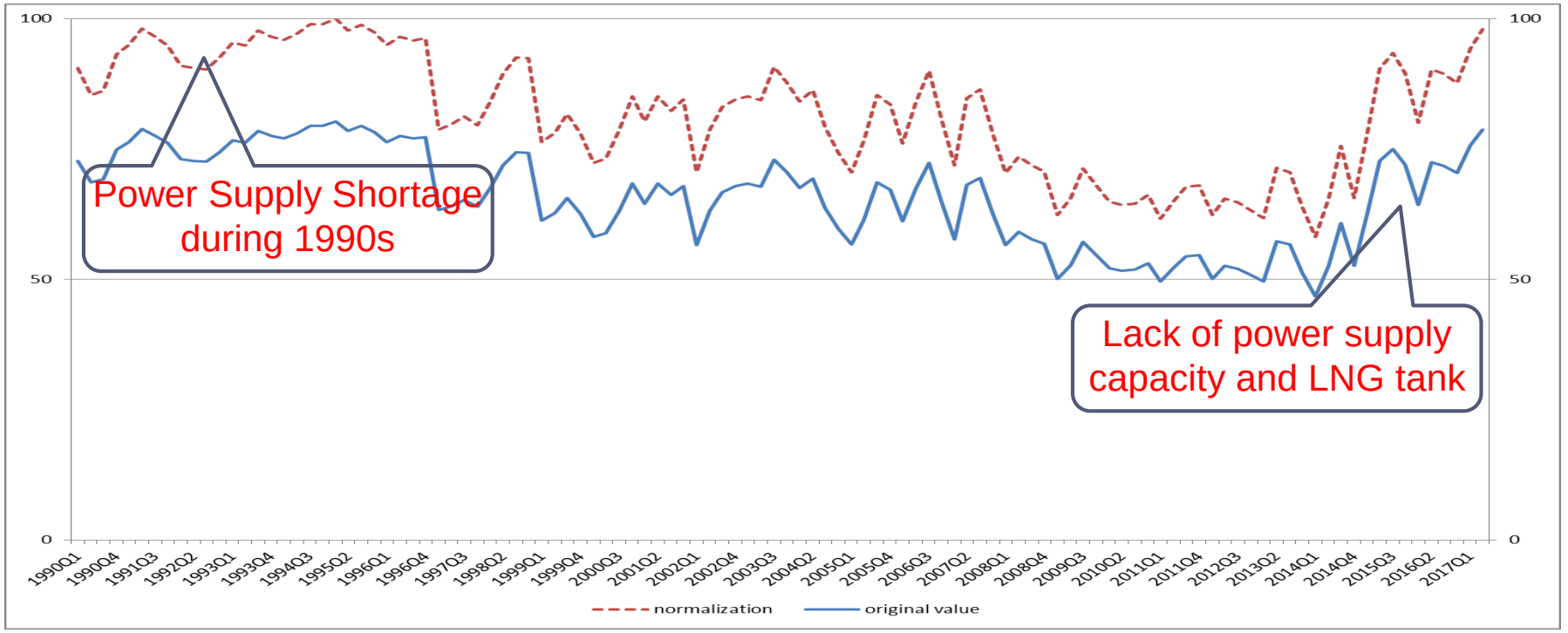


Figure 13: IV of Taiwan

4.3 Vulnerability of End-use Energy Consumption (EEV)

- This trend shows that the improving of final energy consumption mix risk and energy efficiency improvement but the international energy price of coal, oil and natural gas had drastically fluctuation which affects the vulnerability of end-use energy consumption.

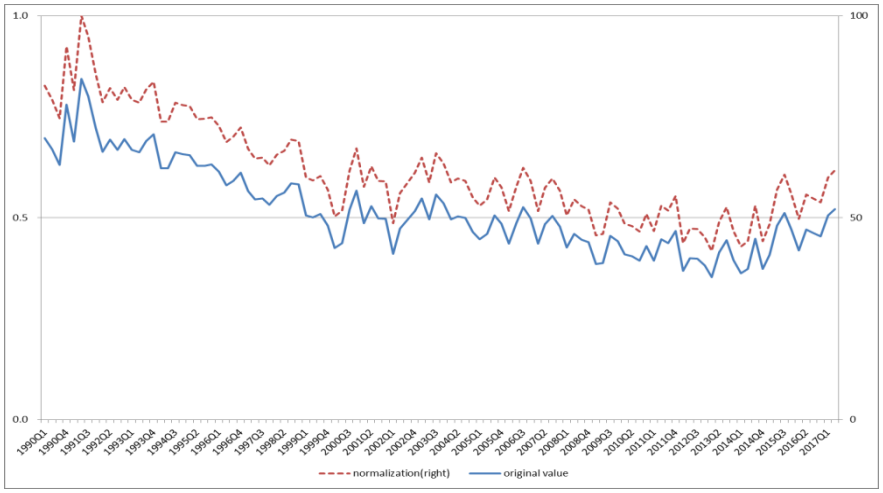


Figure 14: Final Energy Consumption Mix Risk of Taiwan

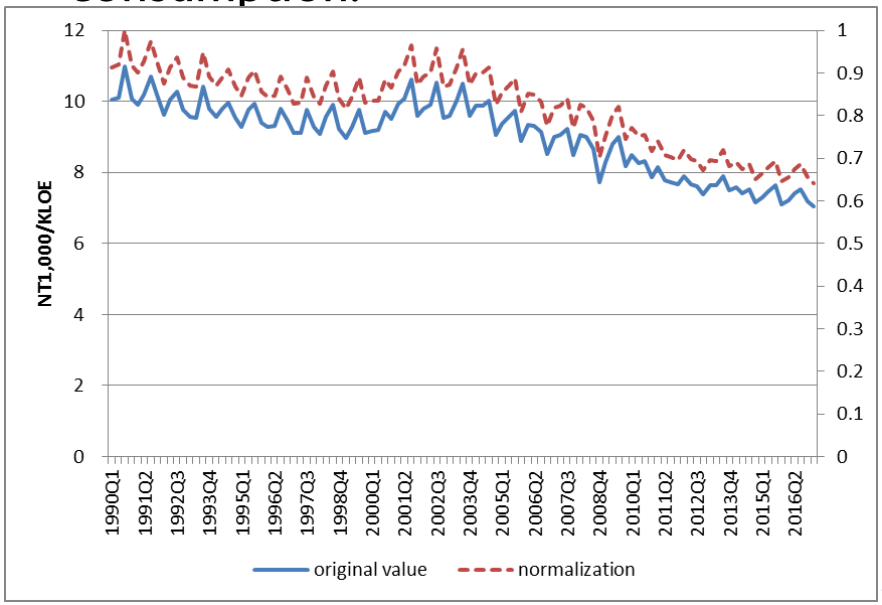


Figure 16: Energy Intensity of Taiwan

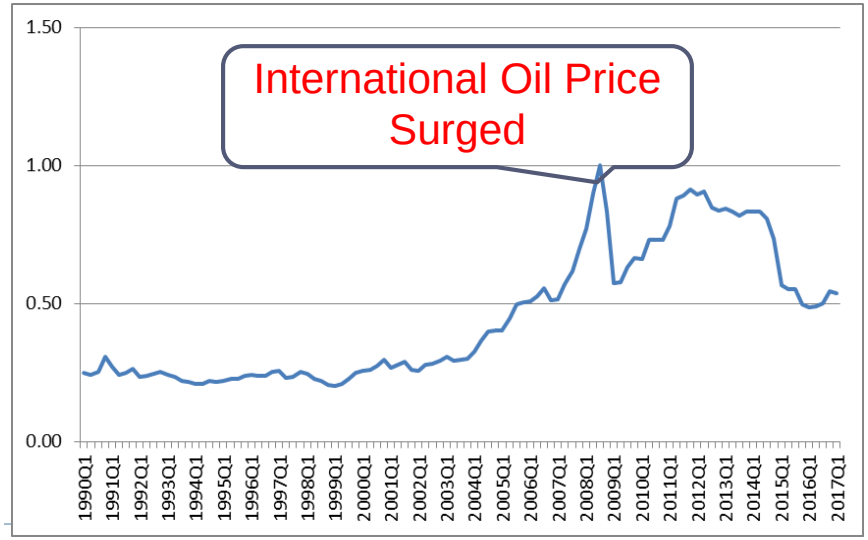


Figure 15: Normalized Energy Price of Taiwan

4.3 Vulnerability of End-use Energy Consumption (EEV)

- The value of EEV decreased from 71.69 in 1990Q4 to 59.54 in 2005Q1. It rebounded to 77.23 in 2008Q3.

- The international oil price surge during 2007 to 2008 lead to rise of EEV.
- EEV then declined to 57.72 in 2016Q4 owing to the drastic decrease in import energy prices.
- EEV had increased after 2017Q1.

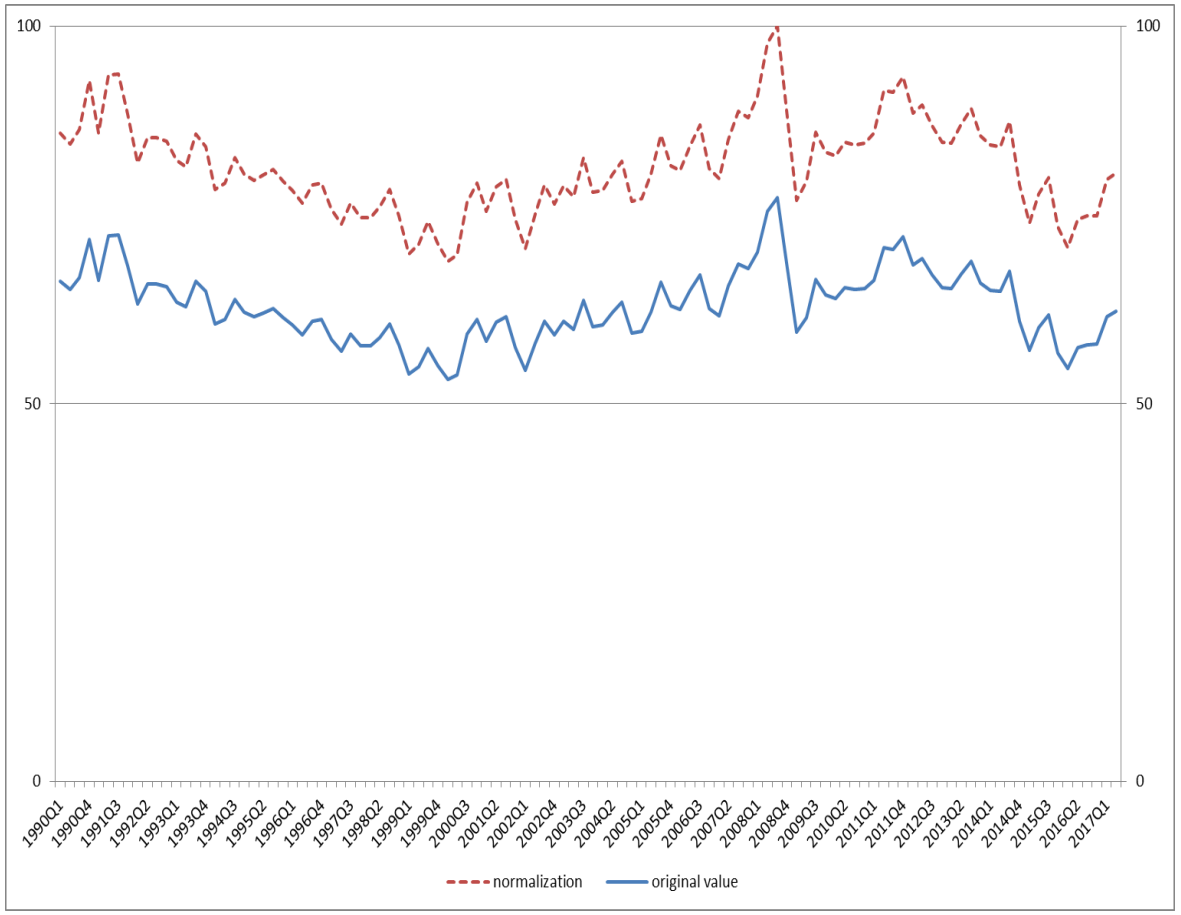


Figure 17: EEV of Taiwan

4.4 Energy Vulnerability (EV)(1/2)

- Choosing the maximum value of PEV, IV or EEV as the value of EV, we compile the EV indicator as Figure 18.

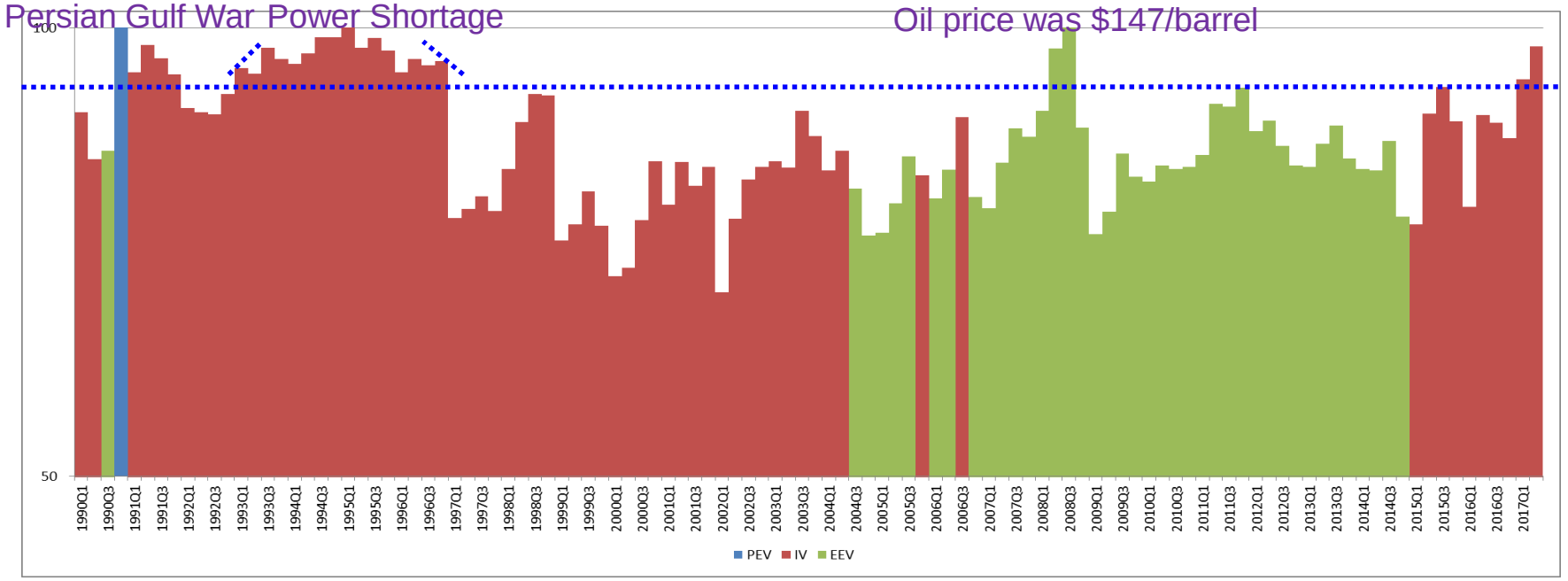


Figure 18: Energy Vulnerability of Taiwan

- With the Exception during Persian Gulf War, the increase of EV was mainly coming from the shortage of energy infrastructure during 1990 to 2003.
- During 2004 to 2014 the EV was deterioration because of international energy price surged.

4.4 Energy Vulnerability (EV)(2/2)

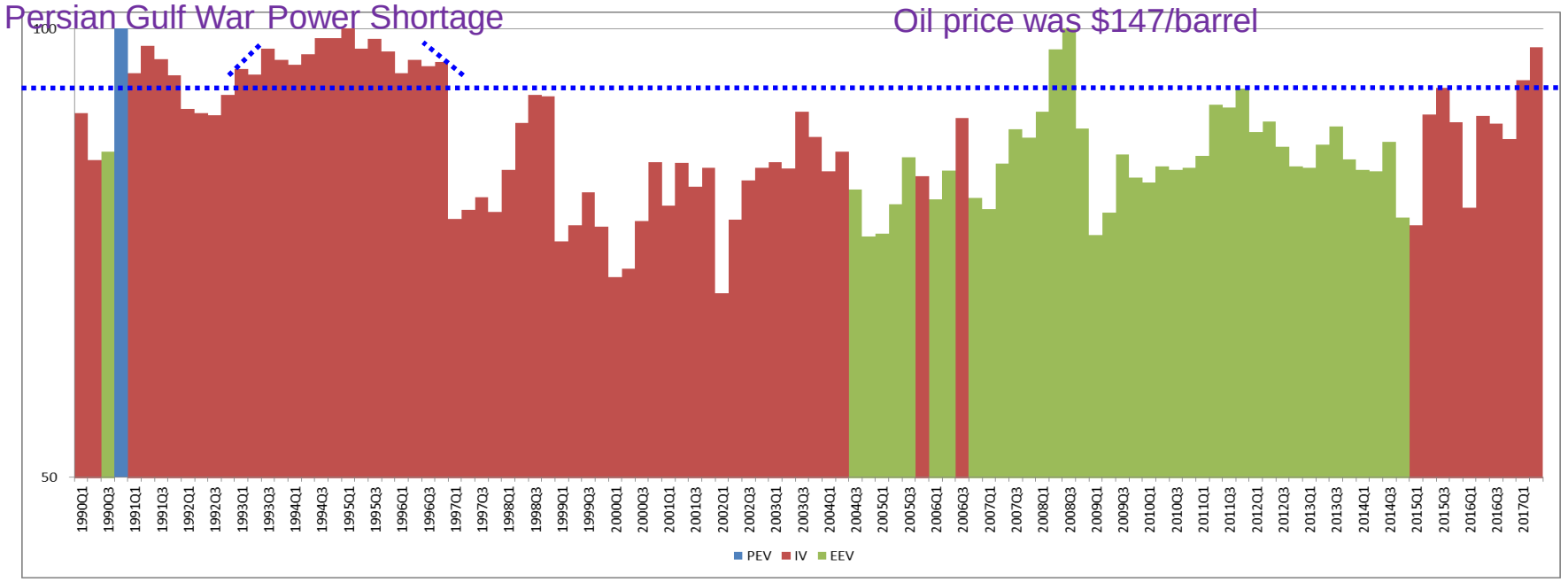


Figure 18: Energy Vulnerability of Taiwan

- Although the IV was decreasing during 1997 to 2014, the shortage of power supply and the Nuclear-Free Homeland Policy adopted by the new government has led to the increase of infrastructure vulnerability during 2014Q4 to 2017Q2, which is approaching to the low reserve margin ratio of 5.36 percent on average that during 1990-1996, in which electricity blackouts happed frequently.

V. Conclusion and Implication

Conclusion

- The empirical outcome shows that the PEV was decreasing because of diversification and importing energy from lower political risk countries.
- In recent years, the IV was rapid deterioration due to lack of the LNG storage capacity and power supply equipment.
- The value of EEV presented the pattern of variation. Although the value of EEV had decreased owing to the improving of final energy consumption mix risk and energy efficiency improvement but the international energy price of coal, oil and natural gas had drastically fluctuation which affects the vulnerability of end-use energy consumption.
- Although the IV was decreasing during 1997 to 2014, the shortage of power supply and the Nuclear-Free Homeland Policy adopted by the new government has led to increase of Energy vulnerability (EV) during 2014Q4 to 2017Q2.

Policy Implication

- The energy transformation policy needs to be reevaluated and modified.
- We need to build-up new capacity of gas, install new power plants, especially base load power plant and enhance demand-side management measures to mitigate the pressure of electricity shortage.
- The energy dependence of Taiwan is higher than 97 percent and the variation of international energy price will deeply affect industry and households. Government should take proactive energy-efficiency policies and re-consider the optimal electricity mix to reduce negative impact from international energy price fluctuation.

Thank you for your attention!