IDRiM (2015) 5 (2) ISSN: 2185-8322
DOI10.5595/idrim.2015.0109

Journal of Integrated Disaster Risk Management

Original paper

A Required Level of Enhancing Life Safety Derived from the Cost for Substituting Nuclear Energy in Japan

Eishiro Higo[1] and Mahesh D. Pandey[1]

Received: 29/01/2015 / Accepted: 12/11/2015 / Published online: 29/12/2015

Abstract Since the disastrous earthquake and tsunami on March 11, 2011, Japanese people have discussed the question of “How safe is safe enough?” The risk of spills from nuclear power plants is one of the major issues, and the government has shut down almost all nuclear power plants to re-evaluate the risk from each one. However, even after the re-evaluation, the nuclear power plants remain closed because many people do not agree with the evaluation, and they prefer to avoid as much risk as possible without fully understanding the cost of their demands. Currently, to sustain the electric demand with thermal power plants, Japan must import more fossil fuel at great cost. This study provides a comprehensible cost-benefit criterion for enhancing life safety. The criterion provides a required level of enhancing life safety which equivalents with the additional cost for substituting nuclear energy and importing other energy sources. This suggested criterion could be used as a benchmark to evaluate the actual reduced risk by prohibiting the nuclear power plants’ operation.

Key words Life quality index, Societal capacity to commit resources, Value of statistic life, Cost-benefit analysis, Nuclear energy.

1. INTRODUCTION

After the nuclear disaster of Fukushima in 2011, the Japanese government has shut down most nuclear power plants. The government is having trouble persuading people to accept the associated risks even after re-evaluation of the nuclear power plants’ safety. Within Japan, many people prefer to prohibit the use of nuclear power plants without fully understanding the cost of their demand. Currently, to sustain the electric demand with thermal power plants, Japan has had to increase its fossil fuel imports; the increased cost is approximately 44 billion Canadian dollars in 2012 (The Federation of Electric Power Companies of Japan 2014).

The problem of the current situation in Japan is that people react to the negative aspects of nuclear power without enough consideration of the benefit. Even if Japan eventually decides not to use nuclear power as an energy source, this decision should be based on a rational discussion. One reason for the lack

[1]Department of Civil and Environmental Engineering, University of Waterloo, Waterloo, Canada
ehigo@uwaterloo.ca, mdpandey@uwaterloo.ca

of objective discussions is that people do not use objective indicators that evaluate risks for human life in monetary terms. People need to know the cost of avoiding risks, and should compare the costs for risk reduction with the costs of reducing other risks. Within a limited budget, people have to decide effective risk reduction policies by comparing the costs.

Among indicators that transfer life risks into monetary costs are the Societal Capacity to Commit Resources (SCCR), derived from the life quality index (LQI). The LQI was originally proposed for an alternative way to represent the wealth of each nation, for which currently GDP is widely used (Nathwani *et al.* 1997). Modifying the LQI, Pandey *et al.* developed the new SCCR criterion to provide a trade-off function between monetary value and mortality risks (Nathwani *et al.* 2009; Pandey *et al.* 2006). The authors calculate the maximum acceptable cost for the given options to reduce mortality risks.

This study calculates a required level of enhancing life safety by transferring the known additional cost for alternative energy sources into the term of life expectancy through the SCCR criterion.

2. RELATED STUDIES

Cost-risk trade-off has been one of the main topics in studies for the regulation of toxic chemicals. In that context, the value of life also needs to be estimated in monetary terms. The well-known value for human life is the “value of statistic life (VSL),” which is calculated from people’s willingness to pay (WTP) for avoiding a risk. In this section, VSL is briefly introduced and compared with the indicator used in this study, LQI.

2.1 Value of statistic life

Value of statistic life (VSL) is a representative value of life, and is based on people’s willingness to pay (WTP) to avoid risks. One major method to deriving VSL uses a wage-risk trade-off approach (the Hedonic Wage method). Mrozek and Taylor review 47 studies of VSL derived by compensating-wage equations, and conduct meta-analysis with 33 VSL studies. A risk premium is derived from the wage differences among jobs, and the differential of compensating-wage equations is converted to VSL (Mrozek and Taylor 2002). Another method, Contingent Valuation, derives the VSL from surveys using questionnaire about WTP for a risk. Referring to 26 results of studies from (Viscusi 1992), in which 21 are from the Hedonic Wage method and five are from the Contingent Valuation method, US Environmental Protection Agency (EPA) finds that the most fitting distribution for varying VSL values is a Weibull distribution with a mean of $7.4 million (in 2006$) (U.S. EPA 2011). Boardmann (2006) refers to three meta-analysis (Miller 2000; Mrozek and Taylor 2002; Viscusi and Aldy 2003) and suggests that the reasonable range of VSL is from $2 million to $6 million. These studies show there is a reasonable range for the VSL in North America even though the VSL value varies depending on each study. The next section introduces LQI and compares it with the VSL values from this section.

2.2 The life-quality index

Originally, the LQI was presented as a function of the real GDP (G $/person/year) and life expectancy (E years/person) (Nathwani *et al.* 1997) as follows:

$$L_0 = G^c E^{1-c} \tag{1}$$

where c is a constant, denoting the annual fraction of work time per person required for producing G. The LQI was derived on the basis of a differential equation of LQI with some restrictions placed on its coefficients. The differential equation approach is considered less intuitive, and there is a need to provide a fuller explanation of for the wider use by decision-makers.

Subsequently, Pandey and Nathwani (2004; 2003a; 2003b) presented a derivation of LQI using the concept of a lifetime utility function and improved its technical foundation. In this formulation, the LQI turns out to be (1 _ c)th root of the original index given in Eq. (1):

$$L_Q = G^{c/(1-c)}\, E \tag{2}$$

This derivation provides a richer explanation of the underlying concepts and it links the LQI to concepts generally understood by practitioners in decision analysis, economic modelling, cost-benefit analysis and risk assessment.

Rackwitz (2002; 2004b) expanded the LQI framework and applied it for the first time to determine optimal safety levels in civil engineering infrastructures. Rackwitz (2004a) also presented an extensive analysis of economic data to support the rationale behind the LQI. Maes *et al.* (2003) applied LQI for optimizing the life-cycle cost of structures. The LQI model has also been applied to the cost-benefit analysis of air quality standards and nuclear safety design practices (Pandey and Nathwani 2004; Pandey and Nathwani 2003a; Pandey and Nathwani 2003b).

VSL and LQI are derived from different principles and methods; however, the equivalent VSL derived from LQI can be conducted and compared with the original VSL. Based on the 1992 Canadian Life Table, Nathwani *et al.* (1997) shows the estimation for the change in life expectancy due to a small change (*dM*) in the mortality rate as follows:

$$\frac{dE}{E} = 19.2dM. \tag{3}$$

Using this transferring indicator, the equivalent VSL in Canada is briefly calculated; it is about 3 million Canadian dollars. This value is in the range of variety of the value of VSL (Boardman 2006), and relatively smaller than the mean value of VSL studies (U.S. EPA 2011).

3. DERIVATION OF SCCR

3.1 General

We present a model to determine an acceptable level of expenditure that can be justifiably incurred on behalf of the public interest in exchange for a small reduction in the risk of death that results in improved life quality for all. This value can be considered as the Societal Capacity to Commit Resources (SCCR). This value was first introduced by Pandey *et al.* (2006), in which the value was named Societal Willingness-to-Pay (SWTP). The proposed approach relies on two major indicators, namely, life expectancy as a measure of safety, and the real gross domestic product per person (GDP) as a measure of the quality of life (United Nations Development Program 1990). It should be commented that life expectancy has been validated over time and again as a universal indicator of social development, environmental quality and public health (Gulis 2000). Both indicators have been in use for half a century to express the wealth and health of a nation in numbers, and they are reliably measured. The Societal Capacity to Commit Resources (SCCR) for a small reduction in risk can be formulated as a problem of decision making under uncertainty.

3.2 Derivation of LQI

3.2.1 Analysis

The general idea in welfare economics is that a person's enjoyment of life-quality or utility in an economic sense arises from a continuous stream of resources available for consumption over the entire life. Therefore, income required to support consumption and the time to enjoy it are two determinants of the life-quality. The potential lifetime utility of a person can be interpreted as the social income (*G* $/person/year) utility over the work-free (leisure) lifetime (t_R). An ordinal utility function can then be defined as

$$L_U = U(G)t_L = \left(\frac{G^q}{q}\right)t_R, \tag{4}$$

where the function, $U(G)$, is the utility in per unit time, since *G* is a rate quantity; and the exponent q is referred to as the elasticity of utility with respect to consumption, which is taken as a constant. This function is commonly used in economic analysis, as it exhibits a constant relative risk aversion (CRRA) equal to $-GU''(G)/\,U'(G) = (1-q)$. The coefficient of risk aversion also determines the person's willingness to shift consumption between different periods; the smaller is h, the more willing the person is to allow its consumption to vary over time (Rimer 2001). In the present context, the utility function of income, $U(G) = G^q/q$, expressed in the Human Development Report (United Nations Development Program 1990), serves to illustrate an important point that the indicator reflects diminishing returns in transforming income into human capabilities.

Considering *G* as a constant and the remaining lifetime is a random variable, the expected utility can be derived as (Pandey and Nathwani 2004; Pandey and Nathwani 2003a; Pandey and Nathwani 2003b)

$$L_Q = \left(\frac{G^q}{q}\right)e_R \tag{5}$$

$$e_R = (1-w)E \tag{6}$$

$$w = \frac{hM}{h_{total}P} \tag{7}$$

where e_R is the work-free life expectancy; w is the work-time fraction; *h* is annual worked hours; h_{total} is the total hours of a year, 8760 hours; *M* is the employment; and *P* is the population.

3.2.2 Production function

The production function, *Y*, is a relationship between the factors of production (input) and the production of goods and services (i.e., GDP) in a period, usually of one year. Labour (*W*) and capital (*K*) constitute the factors of production. Labour refers to the effort (in person hours at work) required for production. Capital is the stock of goods used in the production process. One of the most widely used production functions was proposed by Cobb and Douglas as

$$Y = AK^{\alpha}W^{\beta} \tag{8}$$

where A represents the technological knowledge factor, and α and β are constants that are independent of *K* and *W* (Samuelson 1970). Typically, Eq. (8) is written in terms of index numbers, which are obtained by dividing the current values by those of some base year. For example

$$\frac{Y(t)}{Y_0} = \left(\frac{K(t)}{K_0^\alpha}\right)^\alpha \left(\frac{W(t)}{W_0}\right)^\beta \tag{9}$$

These parameters can be estimated from the analysis of economic production data.

3.2.3 Calibration of LQI

The calibration is based on LQI described in terms of work time and then using the labour-leisure trade-off. Suppose productive work time per person is w year/year and the number of persons in the society is *N*. The total labour input is therefore $W = wN\ year/year$ and capital stock investment as $K = kN\ \$/year$. Substituted in the production function (8)

$$Y = A(kN)^\alpha (wN)^\beta \tag{10}$$

and rearranged as

$$\frac{Y}{N} = G = \mathrm{A(k)}^\alpha (w)^\beta. \tag{11}$$

Now substituting for *G* from Eq. (11) and $e_R = (1-w)E$ into Eq. (5), the LQI can be written as

$$L_Q = \frac{1}{q}(Ak^\alpha)^q \left(w^\beta\right)^q (1-w)E. \tag{12}$$

We assume that the capital investment per person (k) and technological factors (*A*) are independent of the work-time fraction (w). Using the labour-leisure trade-off, the first-order optimality condition is expressed as

$$\frac{dL_Q}{dw} = 0 \Rightarrow q = \frac{1}{\beta}\frac{w}{(1-w)} \tag{13}$$

where $\beta = (sW)/Y = Wages/GDP$, which is derived with an assumption of the profit maximizing decisions as shown by Pandey *et al.* (Pandey, Nathwani and Lind 2006).

The assumption of *k* being independent of *w* is examined by Pandey *et al.* (2006). The use of production function in the LQI derivation was first presented by Pandey [17]. Substituting for G, q and e_R in Eq. (5), the final expression of LQI is obtained as

$$L_Q = (Ak^\alpha)^q \left(\frac{\beta(1-w)}{w}\right) G^q (1-w)E = CG^qE \tag{14}$$

where $C = (Ak^\alpha)^q \left(\frac{\beta(1-w)^2}{w}\right)$ is an unimportant constant.

3.3 Societal Capacity to Commit Resources (SCCR)

3.3.1 Indifference curve and marginal rate of substitution

The assumption of utility maximization is a useful device to explain consumer behaviour. A utility function in this context is only needed to describe an indifference curve in the commodity space, indicating that people are indifferent between various consumption patterns and prefer more to less. The indifference curve, a concept introduced by Edgeworth, is a locus of points for all those combinations of x and y that produce a constant level of utility function $U(x,y)$ as shown in Figure 1, i.e.

$$U(x,y) = C = x^a y^b \tag{15}$$

or it can be written in a differential form as

$$dU(x,y) = 0 = \frac{\partial U(x,y)}{\partial x} dx + \frac{\partial U(x,y)}{\partial y} dy. \tag{16}$$

For the specific power utility function (Eq. (15)), it can be simplified as

$$a\frac{dx}{x} + b\frac{dy}{y} = 0 \tag{17}$$

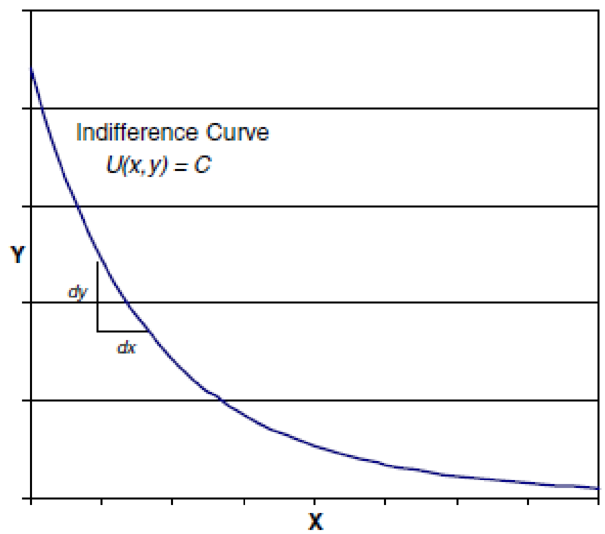

Figure 1. The utility indifference curve (Pandey *et al.* 2006)

The indifference curve is convex to the origin, reflecting the law of diminishing marginal utility. Given a utility function, a scale of preference, and consequently an indifference curve, can be deduced. But it is not possible to deduce a unique utility function from a given indifference equation. There are in general an infinite number of utility functions which can generate a given indifference curve. For example, if we construct one utility function, we can get another by squaring this function or another by taking the logarithm of this function. In fact any monotonic transformation of utility function leave the indifference curve unchanged. In this sense, the utility function is considered indeterminate.

The marginal rate of substitution (MRS) of y for x is defined as the amount of y that the person is willing to give up in order to gain an additional unit of x and still remain on the same indifference curve, i.e., maintain the constant level of utility. Mathematically, it is given as the ratio of marginal utility of x to y

$$MRS_{\mathrm{y-x}} = \frac{\partial \mathrm{U(x,y)}/\partial x}{\partial \mathrm{U(x,y)}/\partial y}. \tag{18}$$

From Eqs. (16) and (17), it can be shown that

$$MRS_{\mathrm{y-x}} = -\frac{dy}{dx} = \frac{a}{b}\frac{y}{x}. \tag{19}$$

Note that $\mathrm{MRS}_{\mathrm{y-x}}$ decreases with increase in x, which is consistent with law of diminishing marginal utility. It is also shown by the convexity of the utility indifference curve in $\mathrm{X-Y}$ coordinates. An important point is that $\mathrm{MRS}_{\mathrm{y-x}}$ is invariant with respect to a monotonic transformation of the utility function.

3.3.2 Societal Capacity to Commit Resources (SCCR)

One important goal in managing risks to life safety is to determine an acceptable level of expenditure that can be justifiably incurred on behalf of the public in exchange for a small reduction in the risk of death without comprising the life-quality. This value can be considered as a fair estimate of the Societal Capacity to Commit Resources (SCCR) for safety. Suppose a small proportion of GDP, dG, is invested in implementing a project, program or regulation that affects the public risk and modifies the life expectancy by a small amount dE. The net benefit criterion requires that there should be a net increase in LQI, which can be derived from Eqs. (1) or (2) as

$$\frac{dL}{L} = \frac{dE}{E} + q\frac{dG}{G} \geq 0 \tag{20}$$

Comparing Eqs. (17) and (20), the condition to evaluate the societal willingness-to-pay implies that the society's preference remains on the same utility indifference curve. There is no other particular meaning of the "LQI invariance principle". The fact that the indifference curve may shift over time is not accounted for in the LQI formulation. A key parameter in the determination of "Societal Capacity to Commit Resources" (SCCR) is the marginal rate of substitution of income (*G*) for lifetime (*E*), which depends on $c/(1-c)$.

The previous LQI calibration (Nathwani *et al.* 1997) assumed a linear relationship between G and w (i.e., b = 1), resulting in a lower value of q from Eq. (13). Similar to Eq. (21), the Societal Capacity to Commit Resources (SCCR) can be defined as

$$SCCR = (-dG) = \frac{G}{q}\frac{dE}{E}. \tag{21}$$

This study uses this SCCR to transfer the cost to avoid a risk to the required level of enhancing life safety, although the SCCR is originally used in opposite translation; it provides a societal willingness-to-pay from the enhancing life safety.

4. APPLICATION AND DISCUSSION

As an application of SCCR, the equivalent mortality risk for the substitute energy for nuclear power is calculated. First, the LQI and SCCR are calculated from the Japanese basic statistics. With the values as variables, the required level of enhancing life safety by substituting nuclear energy is calculated by translating the cost of substitution into equivalent increase of life expectancy. Moreover, for three scenarios, changing the damage durations of substituting nuclear energy, the net present values, and the amounts of repayment are derived and compared.

IDRiM (2015) 5 (2)
DOI10.5595/idrim.2015.0109 ISSN: 2185-8322

4.1 Substitution cost of nuclear energy

After the nuclear disaster of Fukushima in 2011, the Japanese government has stopped most nuclear power plants (see Figure 2).

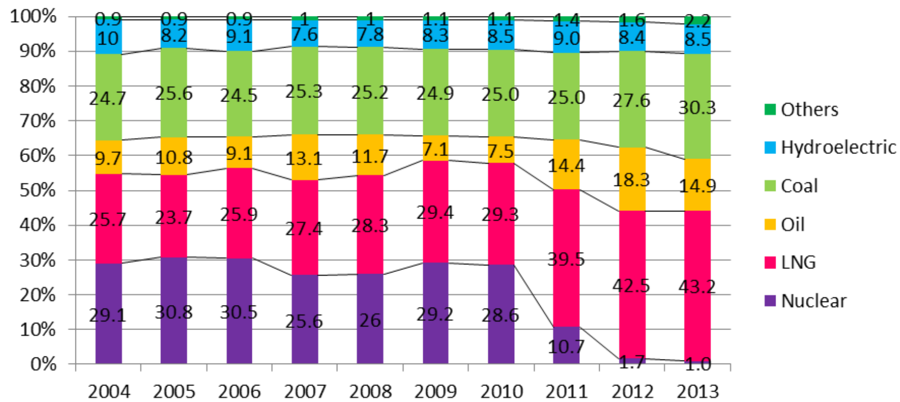

Figure 2. Changes of energy sources in Japan (The Federation of Electric Power Companies of Japan 2014)

The government is in a trouble to persuade the people to accept the nuclear risks even after re-evaluation of the nuclear power plants for safety. Within Japan, many people prefer to prohibit the use of nuclear power plants without considering their benefits. Currently, to sustain the electric demand with thermal power plants, Japan imports more fossil fuel; the increased cost is approximately 44 billion Canadian dollars (The Federation of Electric Power Companies of Japan 2014) (see Figure 3).

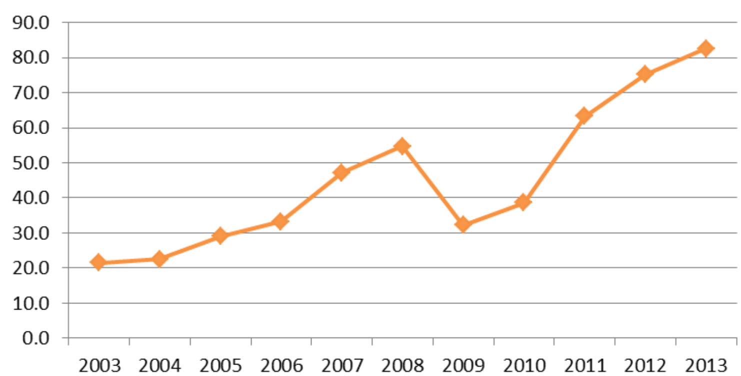

Figure 3. Fuel expenses of Japan (The Federation of Electric Power Companies of Japan 2014)

In detail, the share of LNG power plants increased from 29.3% in 2010 to 43.2% in 2013. Similarly, the share of oil and coal also increased from 7.5% and 25.0% in 2010 to 14.9% and 30.3% in 2013 respectively. The increase for the dependence on thermal power plants directly raises the cost of fuel because the self-sufficiency of the energy production in Japan is quite low (International Energy Agency 2013) (see Figure 4). In the figure, the term “TPES” means total primary energy supply, which is an indicator of the sum of production and imports subtracting exports and storage changes. In short, economic growth depends on energy, including electricity, and in Japan, most fossil fuels are from outside the country. Even though the source of nuclear power, uranium, is also from outside the country, the cost of importing it is much smaller than the cost for other fuel imports. If Japan stops using the nuclear power, the expense for fuel increases. The next section introduces the basic statistics of Japan.

DOI10.5595/idrim.2015.0109
ISSN: 2185-8322

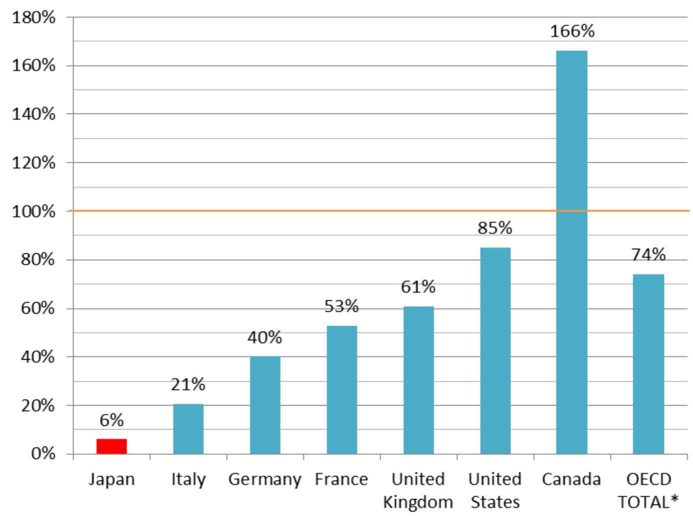

Figure 4. Energy production/TPES (self-sufficiency) (International Energy Agency 2013)

4.2 Economic data of Japan

In this section, the relevant Japanese data is summarized; the data includes GDP, population, life expectancy, employment, annual worked hours, and wage. The data of population and life expectancy is derived from the the Japanese Ministry of Internal Affairs and Communications (Statistics Bureau, Ministry of Internal Affairs and Communications 2011), and the other data is from OECD (OECD 2014). Japan has the third highest GDP index in the world at 5.08 trillion CAD in 2012 (exchange rate is 93.2 JPY/CAD). The average GDP per person for 2010-2012 time period is 41,622 CAD. The population is 127.5 million, which has started to decrease since 2011, while the life expectancy has increased to 79.6 and 86.3 years old for males and females respectively. In this study, for simplification, the life expectancy at birth E(0) is defined as 80 for both genders. Figure 5 shows the trends of population and employment in Japan since 2000; the values are almost constant. In the next section, three parameters for LQI, $\beta, w, and\ q,$ are calculated based on the statistics in this section.

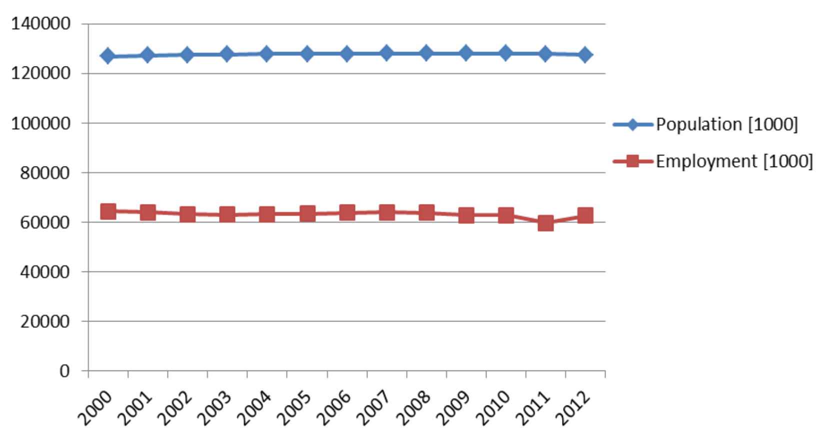

Figure 5. Population and employment in Japan

IDRiM (2015) 5 (2)
DOI10.5595/idrim.2015.0109
ISSN: 2185-8322

4.3 Calibration of the parameters

Based on the Japanese economic data, the parameters of the LQI are revealed as follows:

- The wage to GDP ratio (β) after 2000 in Japan is seem to be stable while it is slightly decreasing; the average value is 0.537 (see Figure 6).
- The work-time fraction per person, for the population (w) or workers only, is almost constant from 2000 to 2012 in Japan; their averages are 0.100 and 0.202 respectively (see Figure 7). In the following analysis, the value for the population (w) is used.

With the values of w and β, the index of the utility function (q) is calculated as Eq. (13). Figure 8 depicts q for each year; the value is almost constant with the average value in Japan from 2000 to 2012 at 0.207.

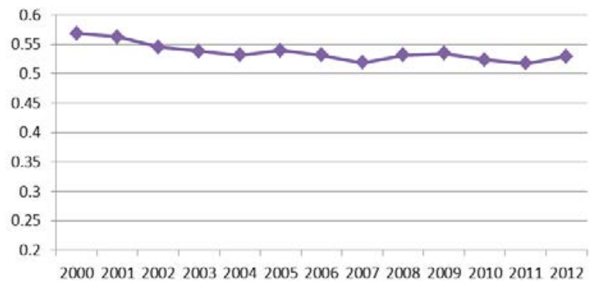

Figure 6. Values of β in Japan

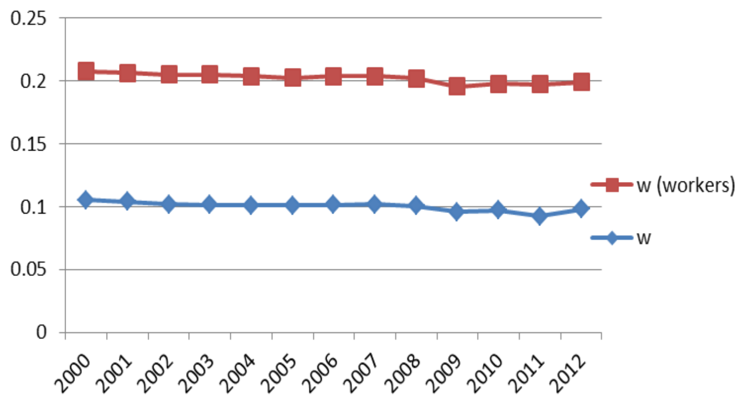

Figure 7. Values of w for workers and all population in Japan

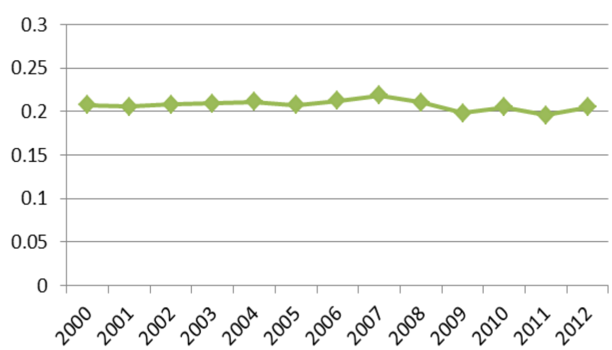

Figure 8. Trend of the index of the utility function (q) in Japan

IDRiM (2015) 5 (2) ISSN: 2185-8322
DOI10.5595/idrim.2015.0109

4.4 Analysis

As Eq. (21) defines, SCCR is the difference of GDP per person (-dG); it is calculated as follows:

$$SCCR = (-dG) = \frac{Additional\ cost\ of\ substitute\ energy\ [CAD/year]}{Population} \\ = 343.5\ [\text{CAD/person/year}]. \tag{22}$$

From Eqs. (21) and (22), using each valuable from 2012, the required level of enhancing life safety in terms of life expectancy, *dE*, is estimated as follows:

$$dE = qE \cdot \frac{SCCR}{G} \\ = 0.1362\ [years/person/life] \\ = 49.72\ [days/person/life]. \tag{23}$$

To roughly grasp how large the number is, similar to Eq. (3), let assume the delta of mortality risk, dM, is set as $\mathrm{dM} = \frac{1}{20}\frac{\mathrm{dE}}{\mathrm{E}}$. The risk of fatality, $\frac{\mathrm{dE}}{\mathrm{E}}$, is $0.1362/80 = 1.71 \times 10^{-3}$ per year. Thus, with the Japanese life table in 2012 (National Institute of Population and Social Security Research n.d.), the life expectancy increase in Eq. (23) has similar impact that 10,901 persons who are supposed to die in a year prolong their lives more than one year in Japan.

Compared with the risk of cancer fatality, 2×10^{-3} per year, the required level of enhancing life safety by substituting nuclear energy is almost the same as the impact of cancer. In other words, unless the fatality risk of nuclear power is estimated significantly larger, more than 1.71×10^{-3} per year, the cost to pay for substituting nuclear power is expensive. In this section, the analysis is conducted based on the assumption that the duration of the additional cost lasts more than the expected life of 80 years. In the next section, the duration is modified, and each scenario is compared with the others.

4.5 Consideration of discount rate and duration of payment

In this section, a net present value (NPV) is calculated with a constant discount rate. In order to estimate the NPV, three scenarios are analyzed. The discount rate is fixed at 5%, which is widely used as a standard. The three scenarios are illustrated as follows:

i. The increase of the fuel expenses will last for more than the life expectancy at birth, 80 years;
ii. The increase of the fuel expenses will last for 30 years;
iii. The increase of the fuel expenses will last for 15 years.

The NPV is calculated as follows:

$$\mathrm{NPV} = \sum_{t=1}^{T} \frac{c}{(1+r)^{t-1}} \tag{24}$$

where *T* is the duration of payments [year] ; *c* is the annual cost [CAD] ; *r* is the discount ratio; *t* represents the time (0 means current year, and 30 means the year 30 years later. Eq. (24) is simplified as follows:

$$\mathrm{NPV} = \mathrm{c}\frac{(1+r)^{\mathrm{T}} - 1}{r(1+r)^{T-1}} \tag{25}$$

and the equivalent payment for each year which amount becomes the NPV is calculated as follows:

$$\sum_{t=1}^{E(0)} \frac{c'}{(1+r)^{t-1}} = NPV \tag{26}$$

$$c' = \mathrm{NPV} \cdot \frac{r(1+r)^{E(0)-1}}{(1+r)^{\mathrm{E}(0)} - 1} = \mathrm{c}(1+r)^{E(0)-T} \frac{(1+r)^{\mathrm{T}} - 1}{(1+r)^{\mathrm{E}(0)} - 1}. \tag{27}$$

where *E(0)* is the life expectancy at birth; c' is the annual repayment for the loan that has the same NPV with one in Eq. (25), and it will be paid over the *E(0)* period. In this study, in order to simplify the analysis, *E(0)* is used as a life expectancy for all the population. The result for each scenario is shown in Table 1. Even though the duration of the damage of substituting nuclear power lasts 15 years, less than one-fifth of the original assumption, the annual repayment is more than half of the original.

Table 1. NPV and annual repayments for three scenarios

Scenario	Duration of Payments [years]	NPV [billion CAD]	Annual Repayments [billion CAD]
(i)	80	905.4	44.0
(ii)	30	710.2	34.5
(iii)	15	479.5	23.3

5. CONCLUSION

Societal Capacity to Commit Resources (SCCR) is derived from life quality index (LQI) originally to estimate an acceptable cost to avoid a risk. For this study, SCCR is used in the opposite order of the original process; with SCCR, an required level of enhancing life safety is counted from the cost to avoid the risk. As an illustration, in Japan, the required level of enhancing life safety by substituting nuclear energy is calculated by transforming the additional cost of fuel expenses, which have risen mainly because of the increase cost of fuel import for substitute energies. For three scenarios, which are differentiated by changing the duration of the additional costs, the total net present values (NPVs) and the annual repayment are calculated.

This study has several limitations. First of all, this study only provides a decision criterion, and the criterion is worthy only when the value is compared with estimated risk reduction by survey or research. Second, the assumption that the increase of fuel expenses represents the decrease of GDP is not supported by economics. For example, we do not consider the impact of electricity charges. The raise of the charges will become a great hindrance for companies in Japan, and some of them may relocate their factories outside of Japan to avoid the additional cost. This acceleration of hollowing out of industries will damage the Japanese economy, and decrease the GDP more than the direct impact of fuel imports. Third, this study does not consider economic damage of nuclear accidents. In order to provide an objective indicator to decide how much risk Japan will take, an extension of this analysis, which conducts more precise cost-benefit analysis, is needed.

DOI10.5595/idrim.2015.0109

ACKNOWLEDGEMENT

The authors would like to thank the anonymous referees for useful suggestions that helped us to improve the original manuscript. The authors also appreciate the editors of the journal.

REFERENCES

Boardman, Anthony E. (2006), "Cost-benefit analysis : concepts and practice (3rd edition)." Upper Saddle River, N.J. : Pearson/Prentice Hall .

Gulis, Gabriel (2000). "Life expectancy as an indicator of environmental health." European journal of epidemiology Vol.16, No. 2, pp.161-165.

International Energy Agency (2013). "Statistics Energy Balances o OECD Countries."

Maes, Marc A., Pandey, Mahesh D., and Nathwani, Jatin S. (2003), "Harmonizing structural safety levels with life-quality objectives." Canadian Journal of Civil Engineering Vol.30, No. 3, pp.500-510.

Miller, Ted R (2000). "Variations between countries in values of statistical life." Journal of Transport Economics and Policy, pp.169-188.

Mrozek, Janusz R., and Taylor, Laura O. (2002). "What Determines the Value of Life? A Meta-Analysis." Journal of Policy Analysis and Management Vol.21, No. 2, pp.253-270.

Nathwani, Jatin S., Pandey, Mahesh D., and Lind, Niels C. (2009). Engineering Decisions for Life Quality: How Safe is Safe Enough? Springer.

Nathwani, Jatin S., Lind, Niels C., and Pandey, Mahesh D. (1997). Affordable Safety By Choice: The Life Quality Method. Waterloo: Institute for Risk Recearch.

National Institute of Population and Social Security Research. All Japan: Life Table Data Series. n.d. http://www.ipss.go.jp/p-toukei/JMD/00/index-en.html (accessed Oct 22, 2015).

OECD. Online OECD Employment database. Jul 14, 2014. http://www.oecd.org/employment/emp/onlineoecdemploymentdatabase.htm#unr.

Pandey, Mahesh D., and Nathwani, Jatin S. (2003a). "A conceptual approach to the estimation of societal willingness-to-pay for nuclear safety programs ." Nuclear engineering and Design Vol.224, pp.65-77.

Pandey, Mahesh D., and Nathwani, Jatin S. (2003b). "Canada Wide Standard for particulate matter and ozone: Cost-benefit analysis using a life-quality index." Risk Analysis Vol.23, No. 1, pp.55-67.

Pandey, Mahesh D., and Nathwani, Jatin S. (2004). "Life quality index for the estimation of societal willingness-to-pay for safety." Structural Safety Vol.26, No. 2, pp.181-199.

Pandey, Mahesh D., Nathwani, Jatin S., and Lind, Niels C. (2006). "The derivation and calibration of the life-quality index (LQI) from economic principles." Structual Safety Vol.28, No. 4, pp.341-360.

Rackwitz, Rüdiger (2002). "Optimization and risk acceptability based on the life quality index." Structural Safety Vol.24, No. 2, pp.297-331.

Rackwitz, Rudiger (2004a). "The philosophy behind life quality index and empirical verification ." Memorandum to Joint Committee on Structural Safety.

Rackwitz, Ruediger (2004b). "Optimal and acceptable technical facilities involving risks." Risk Analysis Vol.24, No. 3, pp.675-695.

Rimer, David (2001). Advanced macroeconomics. Boston: McGraw-Hill.

Samuelson, Paul A. (1970). Economics. 8th. New York: McGraw-Hill.

Statistics Bureau, Ministry of Internal Affairs and Communications (2011). Basic Complete Tabulation on Population and Households. Oct 26, 2011. http://www.stat.go.jp/english/data/kokusei/2010/summary.htm (accessed 7 14, 2014).

The Federation of Electric Power Companies of Japan. "Regular Press Conferences (in Japanese)." 5 23, 2014. http://www.fepc.or.jp/about_us/pr/kaiken/index.html (accessed 8 24, 2014).

U.S. EPA (2011). "The Benefits and Costs of the Clean Air Act from 1990 to 2020."

United Nations Development Program (1990). The human development report. UK: Oxford University Press.

Viscusi, Kip W. (1992). Fatal tradeoffs public and private responsibilities for risk. New York: Oxford University Press.

Viscusi, Kip W., and Aldy Joseph E. (2003) "The Value of a Statistical Life: A Critical Review of Market Estimates throughout the World." NBER Working Paper No.9487.