Evaluation of post-Kyoto frameworks focusing on sector-based approaches and national numerical targets

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Abstract. Since the fourth assessment report of IPCC was published in 2007, the worldwide concern on climate change has been growing unprecedentedly. While the first commitment period of Kyoto Protocol already started from this year, international negotiation has begun on a framework in the next period, what is often called the "post-Kyoto framework". We need to explore efficient and fair institution of mitigating climate changes on the post-Kyoto framework. Under these circumstances, sector-based approaches are attracting attention, since it is not only promising to economically reduce greenhouse gas emissions, but also expected to be accepted by developing countries. In sector-based approaches, each nation set numerical targets as greenhouse gas intensities in individual sectors including industry, residence or transportation, so that they commit to reduce these intensities to realize the targets.

In this paper, we first proposed the methodology combining cross-impact method and Bayesian inference to project what type of institution will be adopted as post-Kyoto frameworks. Computed results identified the several frameworks as post-Kyoto candidates with high probabilities. Then we evaluated the candidates for post-Kyoto frameworks. For this purpose, analytic hierarchy process is applied, taking account of reduction of greenhouse gases, economic impact, possibility of making consensus, and initiative in global negotiation. The evaluated result indicated that the framework has the highest score, in which industrialized and developing countries adopt national numerical target and partial sector-based approaches, respectively. Even if the national numerical targets are imposed as the post-Kyoto framework, we can apply the concept of a sector-based bottom-up approach to set rational numerical targets by summing up GHG emissions in individual sectors. We concluded that sector-based approaches are effective for both industrialized and developing countries.

Keywords: post-Kyoto frameworks, sector-based approaches, national numerical target, Bayesian inference, cross-impact method, analytic hierarchy process

1. Introduction

Since the fourth assessment report of IPCC was published in 2007, worldwide concern on global warming has been escalating unprecedentedly. Response strategies to climate change were raised as the most important issue also in the Heiligendamm summit in June, 2007. Since the first commitment period started this year, they are making the sincere effort to comply with the numerical target in Annex-one countries ratifying Kyoto Protocol.

On the other hand, international negotiation has also started from COP13 in 2007 on the framework to mitigate climate change after 2013, what we call post-Kyoto framework. Japanese government advocated sector-based approaches as post-Kyoto candidates. Taking these situations into consideration, this paper aims at analyzing the post-Kyoto framework, centered on sector-based approaches.

2. Examination of post-Kyoto frameworks

As long as Kyoto Protocol is concerned, United States of America already resigned from the protocol. Developing countries do not have national numerical targets in the protocol, even if they are ratifying it. Furthermore, Kyoto mechanisms are presently not functioning ideally due to complicated certification procedures of CDM. Therefore involvement of developing countries through Kyoto mechanisms is not very efficient for the moment. It is significant to establish a post-Kyoto framework enabling meaningful participation of the United States and developing countries.

Various proposals are already made on the post-Kyoto frameworks including sector-based approaches. In general, sector-based approaches set targets on energy efficiency or greenhouse gas emission intensity on individual sectors including industry, residence or transportation, in which they improve to realize the targets (Schmidt et al., 2006).

In Davos meeting in January, 2008, Japanese Prime Minister, Mr. Fukuda advocated a sector-based bottom up approach, in which each nation is able to evaluate rational numerical target by summing up greenhouse gas emission in each sector. The greenhouse gas emission in each sector is determined by setting a target on its greenhouse gas emission intensity. On the other hand, Japanese government also advocated another type of a framework, cooperative sector-based approach. This approach adopts some key sectors, in which they improve greenhouse gas emission intensities worldwide by transferring efficient technologies. In this sense, the cooperative sector-based approach is closely related with mechanisms for technology transfer such as CDM. Thus sector-based approaches have wide institutional variations. The above classification depends on whether a sector-based approach is for national or international framework. We have also to take account of the classification based on whether it is for all sectors or part of sectors, and whether it is with or without technology transfer.

Taking these factors into consideration, we propose the following classification for sector-based approaches including national numerical targets as in Kyoto Protocol.

① Complete sector-based approach

In this institution, all domestic GHG emissions are classified into individual sectors. For instance, they are divided into GHG emission in iron and steel, cement, pulp and paper, etc. in industry. In the same way, GHG emissions are classified into each sector also in residence, transportation and energy conversion. This approach sets targets on energy efficiency or greenhouse gas emission intensity on individual sectors, which they improve to realize.

② Complete sector-based approach with a mechanism for technology transfer

This institution is the same as the above mentioned complete sector-based approach except for the following point. Namely, this institution recognizes technology transfers without the present complicated certification as CDM by setting simple benchmarks for GHG intensities.

③ Partial sector-based approach

So as to realize the above-mentioned complete sector-based approach, we have to prepare data inventories on GHG emission intensities of all sectors. However, it might be difficult to

prepare the reliable inventories in some sectors. Therefore they deal only with energy intensive sectors with reliable data such as iron and steel, cement and electric power generation in the partial sector-based approach. Then this approach sets targets on energy efficiencies or greenhouse gas emission intensities on the above key sectors to realize the targets.

④ Partial sector-based approach with a mechanism for technology transfer
This institution is the same as the above mentioned partial sector-based approach except for the following point. Namely, this institution recognizes technology transfers without the present complicated certification as CDM by setting simple benchmarks for GHG intensities for energy intensive industries separated from national numerical targets. Namely, this corresponds to the cooperative sector-based approach in Mr. Fukuda's proposal.

⑤ Overall national numerical target
National numerical targets are also included in our analyses, which are imposed to Annex-one countries in Kyoto Protocol. As described above, we could utilize the concept of sector-based approaches even in the national numerical targets, in which we sum up GHG emissions of individual sectors to identify rational numerical targets. Namely, this includes the bottom-up sector-based approach.

3. Projections on the post-Kyoto frameworks

It is useful to identify frameworks of high probability of realization in future. Here we estimate likelihood of realizing each framework. For this purpose, we propose a methodology combining cross-impact method and Bayesian inference.

In the cross-impact method, we solve the quadratic programming problem as shown in Equation (1) to acquire solution.[2)] The Criterion to be minimized is shown in Equation (1). Table 3 shows the seven basic events, of which combination likelihoods are estimated by the cross-impact method. Seven basic events generate $2^7=128$ kinds of scenarios, since each event has two consequences, 1 or 0.

$$J=\sum_i\Big[P(i)-\sum_k\theta_{ik}\pi_k\Big]^2+\sum_i\sum_j\Big[P(i\mid j)P(j)-\sum_k t_{ijk}\pi_k\Big]^2\rightarrow\min \qquad (1)$$

$$\text{subject to:}\quad 0\le\pi_k\le 1\ \left(k=1,2,\cdots,2^n\right)\qquad \Sigma\pi_k=1$$

In the cross-impact model, E_k means scenario k, which is determined by combination of seven kinds of basic events. On the other hand, e_i is a basic event i. For each scenario, π_k implies a likelihood of the scenario, E_k, where P(i) corresponds to a likelihood of e_i. P(i|j) means conditional likelihood. Regarding P(i) and P(i|j), θ_{ik} is a pseudo variable for scenario k to be 1 with generation of e_i, and to be 0 without generation of e_i, where t_{ijk} is a pseudo variable for scenario k to be 1 with generation of both e_i and e_j, and to be 0 in the other cases.

Table 1 shows the seven basic events, of which combination likelihoods are estimated by the cross-impact method. Seven basic events generate $2^7=128$ kinds of scenarios, since each event has two consequences, 1 or 0.

It is difficult to directly estimate likelihoods of 128 scenarios even for experts. In the cross-impact method, we have only to estimate probabilities for seven single events, and to estimate conditional probabilities for combinations of every two events by expert judgments. Then we can estimate likelihoods of the hundred and twenty eight scenarios to minimize the probabilistic contradictions denoted in Equation (1).

As actual procedures, we sent questionnaires to the twelve experts and obtained the expert judgments. We solved the above quadratic programming for these estimates. Then we averaged the calculated probabilities of 128 scenarios among the thirteen expert judgments.

Table 1. Seven basic events adopted in the cross-impact method.

A_1	National numerical targets will be imposed as the first commitment period in industrialized countries.
A_2	National numerical targets will be imposed as the first commitment period in developing countries.
A_3	GHG emissions from energy intensive industries will be dissociated from national numerical targets and managed by sector-based approach in industrialized countries.
A_4	GHG emissions from energy intensive industries will be dissociated from national numerical targets and managed by sector-based approach in developing countries.
A_5	Flexibility measures such as CDM in Kyoto Protocol will be diffused worldwide.
A_6	GHG emissions from all sectors will be managed by sector-based approach in industrialized countries.
A_7	GHG emissions from all sectors will be managed by sector-based approach in developing countries.

After the cross-impact evaluation, the world experienced a few significant events on post-Kyoto negotiation, such as Davos meeting and Toya-lake summit in Table 2. Therefore we adopted Bayesian inference to consider information from these events. According to Bayes' theorem, we can improve quality of our projection empirically by the following equation. We are able to utilize the equation (2) as a recursion formula. Namely, posterior probability, $P(A_i'/event_k)$ after an event_k is able to be used as prior probability before a next event_{k+1}.

$$P(A_i'/event_k)=\frac{P(A_i)P(event_k/A_i)}{\sum_j P(A_j)P(event_k/A_j)} \quad (2)$$

$P(A_i'/event_k)$: Conditional probability of A_i in generation of an event_k

$P(A_i)$: Probability of Ai before an event_k

$P(event_k/A_i)$: Conditional probability of an event_k in generation of A_i

Table 2. The events influencing the post-Kyoto negotiation.

$Event_1$	In COP13 meeting in 2007, Japanese government advocated the cooperative sector-based approach, which was included in the Bali Action Plan.
$Event_2$	In Davos meeting in January, 2008, Japanese Prime Minister, Mr. Fukuda advocated the sector-based bottom up approach, in which each nation is able to evaluate rational numerical target by summing up greenhouse gas emission in each sector.
$Event_3$	Chinese paramount leader, Hu Jintao visited Japan in May, 2008 to meet Japanese prime minister, Fukuda. After the meeting, he stated that sector-based approaches are significant measures to reduce worldwide greenhouse gas emissions.
$Event_4$	In Toya-lake summit, they concluded that bottom-up sector-based approach is useful to set rational numerical targets for developed countries. At the same time, they also confirmed that cooperative sector-based approach is also effective to reduce worldwide greenhouse gas emissions through technology diffusion.

Actual procedures are as follows to combine the cross-impact method and Bayesian inference for quantifying the probability of post-Kyoto scenarios.

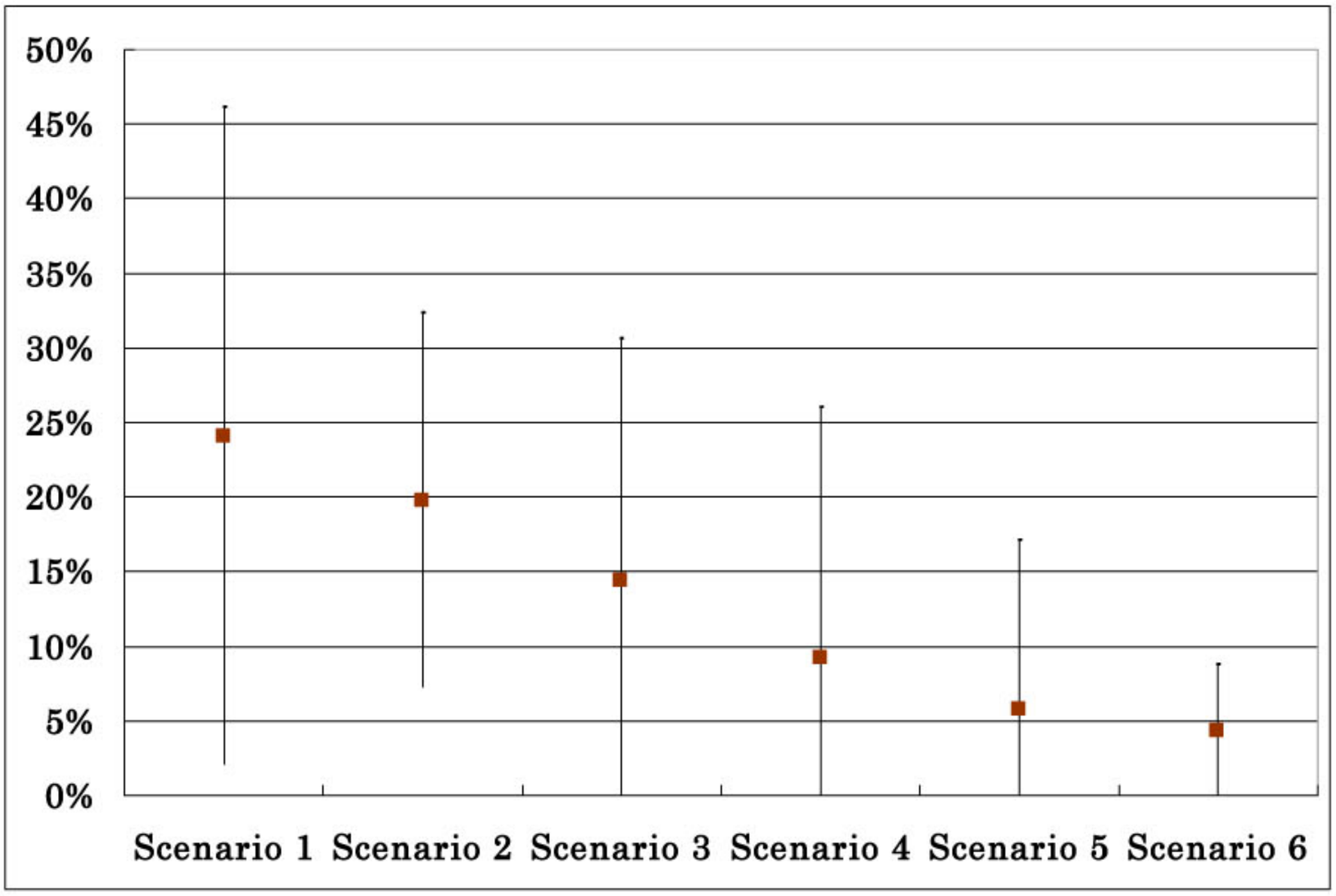
(1) We sent the questionnaires to the twelve experts after the above $event_1$.
(2) Based on the responses, we applied the cross-impact method to quantify probabilities of the hundred and twenty eight post-Kyoto scenarios. Namely, these probabilities are estimated before the $event_2$, $event_3$, and $event_4$.
(3) We applied the Bayesian inference to include influences of the $event_2$, $event_3$, and $event_4$. We revise $P(A_i)$(i=1,2,$\cdots$, 7) of the responses of all experts, using the equation (2).
(4) Based on the revised $P(A_i)$, we applied the cross-impact method once more to quantify probabilities of hundred and twenty eight post-Kyoto scenarios. Namely, these probabilities are estimated taking the influence of the $event_2$, $event_3$, and $event_4$ into consideration.

Figure 1 shows likelihoods of the post-Kyoto frameworks estimated by the cross-impact method in the above procedure (4). Namely, these probabilities are estimated taking the influence of the $event_2$, $event_3$, and $event_4$ into consideration. In particular, it shows six in the hundred and twenty eight scenarios with high probabilities. In the figure, the points are average values of cross-impact estimates based on the twelve expert judgments, while the bars around the points express two times of standard deviations in the estimates.

The national numerical targets for industrialized countries are adopted in five out of the six scenarios. Among the five scenarios, Scenario 1 has the highest average probability more than twenty percentages, in which developing countries do not have any obligations but flexibility measures. In this sense, Scenario 1 is similar to the framework in Kyoto-protocol. The other scenarios, Scenario 2 and 3 have relatively high probabilities between ten and twenty percentages, in which developing countries adopt the partial sector-based approach and the complete sector-based approach with flexibility measures, respectively. The other two scenarios are Scenario 4 and 5. In Scenario 4, developing countries adopt partial sector-based approach, while they do not have any obligations in Scenario 5.

In four out of the six scenarios, the complete or the partial sector-based approaches are adopted in industrialized or in developing countries. Even if the national numerical targets are imposed as the post-Kyoto framework, the concept of the bottom-up sector-based approaches can be adopted to set rational targets. Thus the likelihood of sector-based approaches is not low from

present circumstances.



I.C.; Industrialized countries, D.C.; Developing countries
Scenario 1; IC NUMERICAL／DC FLEXIBILITY MEASURES
Scenario 2; I.C. NUMERICAL／D.C. PARTIAL SECTORAL WITH FLEXIBILITY MEASURES
Scenario 3; I.C. NUMERICAL／D.C. COMPLETE SECTORAL WITH FLEXIBILITY MEASURES
Scenario 4; I.C. NUMERICAL／D.C. PARTIAL SECTORAL
Scenario 5; I.C. NUMERICAL
Scenario 6; I.C. PARTIAL SECTORAL／D.C. PARTIAL SECTORAL WITH FLEXIBITY MEASURES

Figure 1. Likelihoods of the post-Kyoto frameworks estimated by the cross-impact method.

Figure 2 compares the probabilities of the six most probable scenarios before and after the events. In particular, the probabilities in scenario 2, 3 and 4 drastically increased by influence of the $event_2$, $event_3$, and $event_4$. For instance, they concluded that cooperative sector-based approach is effective to reduce worldwide greenhouse gas emissions through technology diffusion. These incidents increased the probabilities of scenario 2, 3 and 4, in which sector-based approaches are adopted in developing countries.

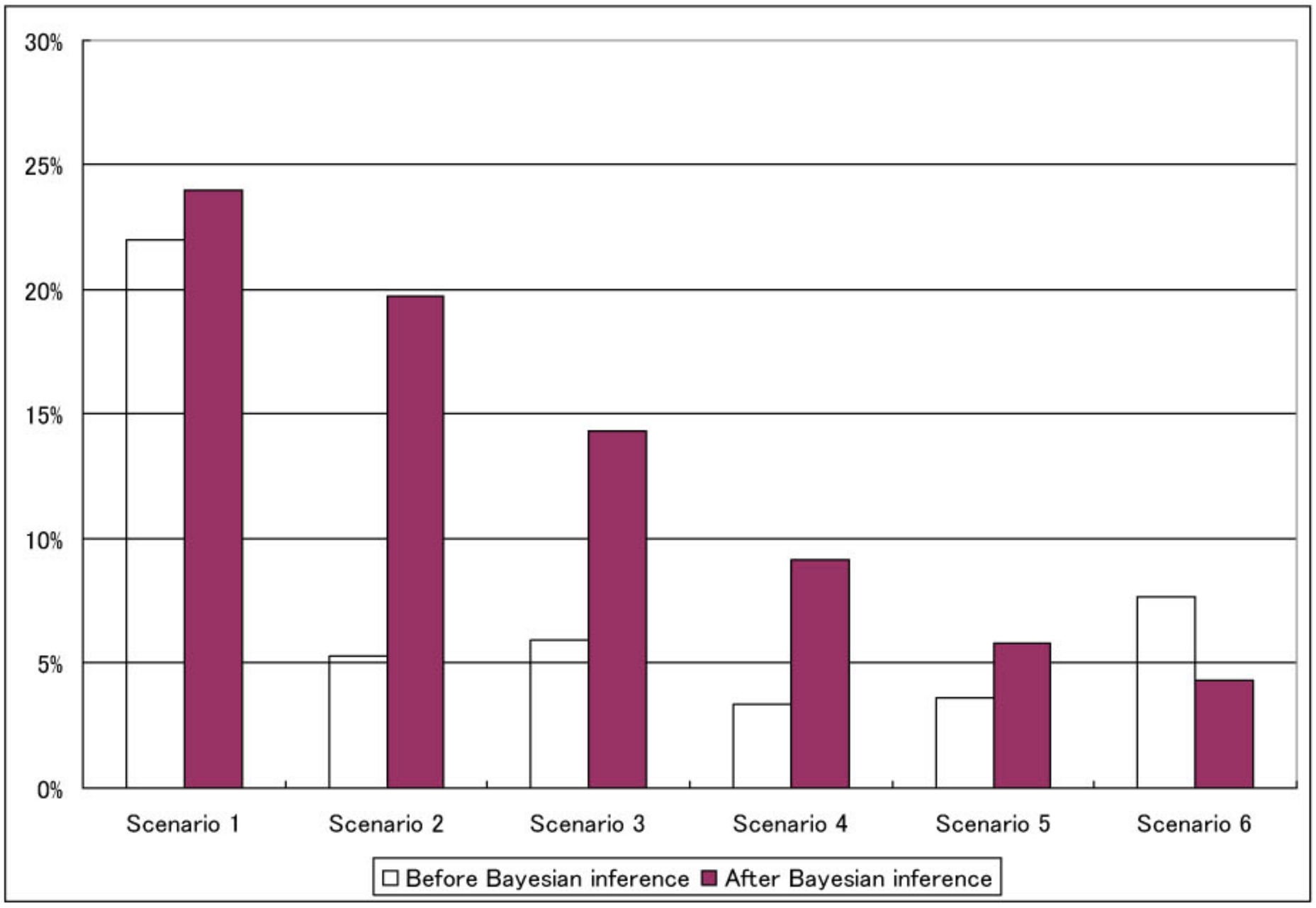
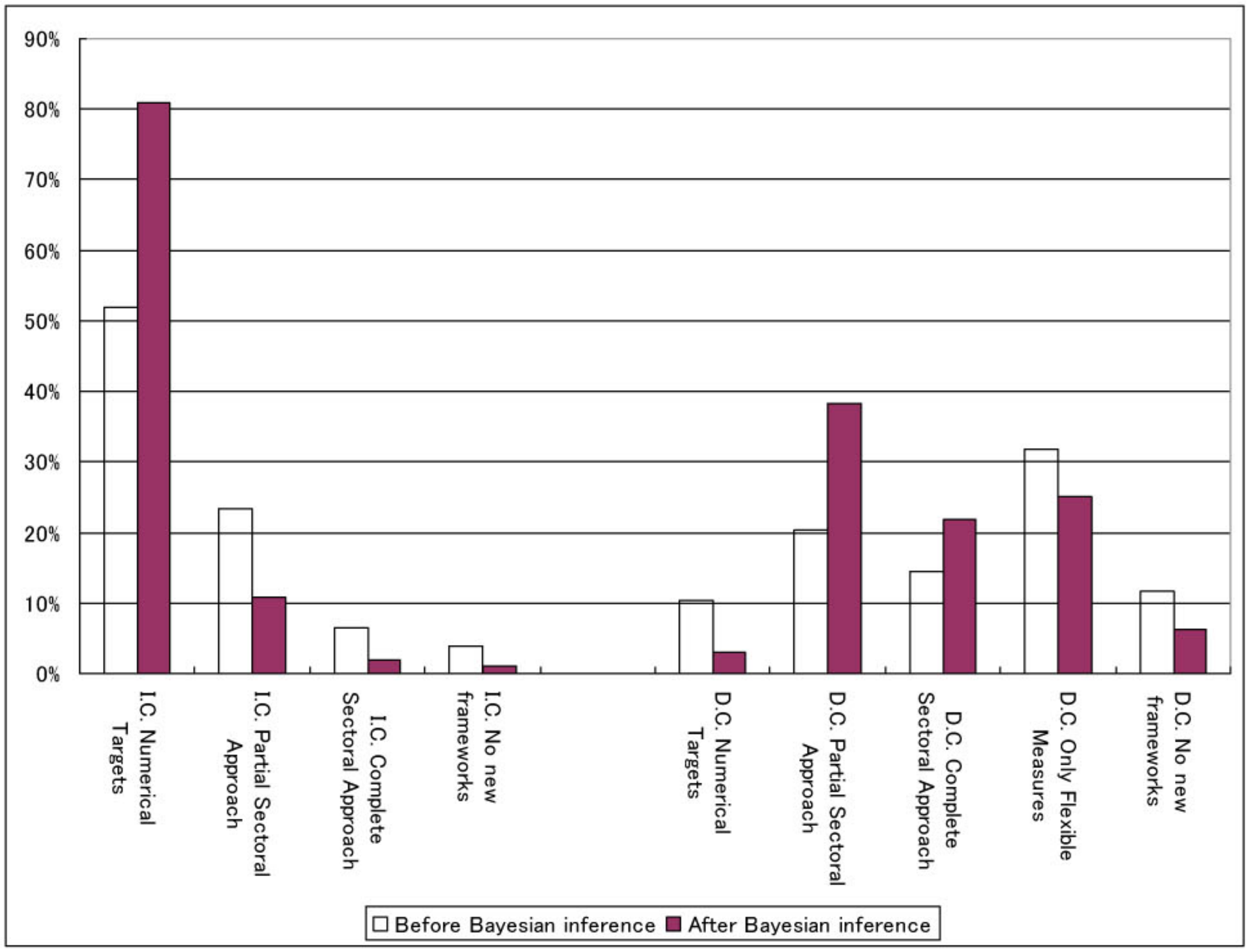


Figure 2. Likelihoods of the post-Kyoto frameworks estimated by the cross-impact method.

Figure 3 shows integrated probabilities of post-Kyoto frameworks in the hundred and twenty eight scenarios taking the events into consideration. For instance, we sum up probabilities of scenarios, in which national numerical targets are adopted in developed countries, as far as the left bar is concerned. In developed countries, the probability of national numerical target is high around eighty percentage points. In Toya-lake summit, they concluded that the bottom-up sector-based approach is useful to set rational numerical targets for developed countries. These incidents increased the probabilities of national numerical targets in developed countries. On the other hand, probabilities of sector-based approaches became high in developing countries.



I.C.; Industrialized countries, D.C.; Developing countries

Figure 3. Summed Likelihoods of the post-Kyoto frameworks in Industrialized and Developing Countries.

4. Comparative analyses on the post-Kyoto frameworks

In this article, we made a comparative analysis of the above six frameworks by Analytic Hierarchy Process based on the structure shown in figure 4. Regarding criteria on the post-Kyoto frameworks, we need to include economic impacts, participation of developing countries and making consensus and so on as well as mitigating climate change.

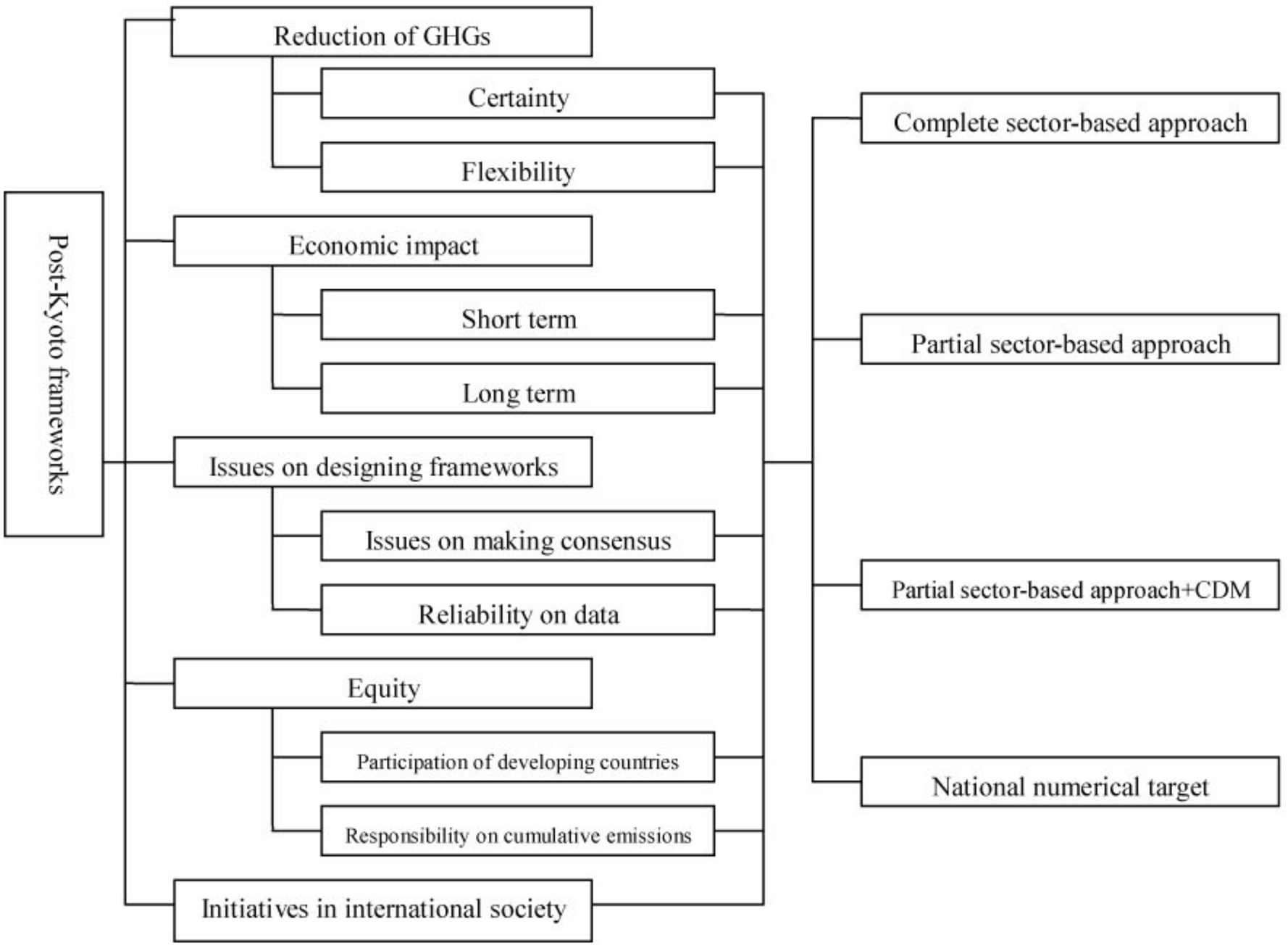
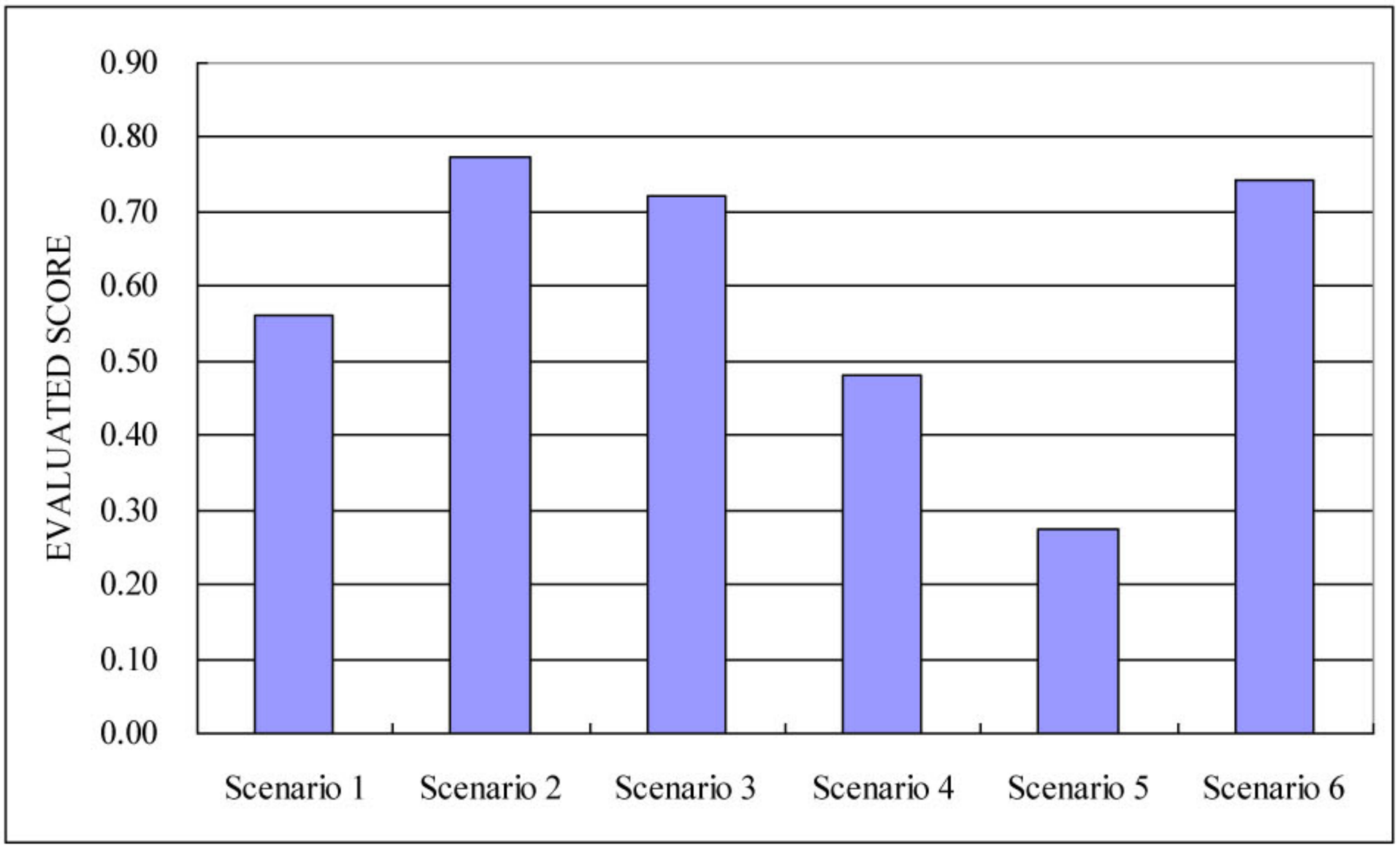


Figure 4. The structure of evaluating the post-Kyoto frameworks.

Weights of each criterion were estimated by Eigenvectors of pair-wise comparison matrices, as shown in table 3.

Table 3. Weights of criteria and sub-criteria in the post-Kyoto frameworks

Criteria	Sub-criteria	Weights of criteria	Weights of sub-criteria
Reduction of GHGs	Certainty	31.7%	15.8%
	Flexibility		15.8%
Economic impact	Short term	28.9%	18.3%
	Long term		10.6%
Issues on designing frameworks	Issues on making consensus	18.3%	11.6%
	Reliability on data		6.7%
Equity	Participation of developing countries	10.6%	5.3%
	Responsibility on cumulative emissions		5.3%
Initiatives in international society		10.6%	10.6%



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Scenario 4; I.C. NUMERICAL／D.C. PARTIAL SECTORAL
Scenario 5; I.C. NUMERICAL
Scenario 6; I.C. PARTIAL SECTORAL／D.C. PARTIAL SECTORAL WITH FLEXIBITY MEASURES

Figure 5. Evaluated scores of the post-Kyoto frameworks by AHP

Estimated results of the six scenarios identified in the last chapter are shown in the figure 5. As a result of AHP, Scenario 5, in which only developed countries adopt national numerical targets, has the lowest score. This is mainly because certainty and flexibility in reducing greenhouse gas emissions is low. Scenario 1, in which developing countries accept only flexibility measures, has also a relatively low score less than 0.6, mainly because certain reduction of greenhouse gas is not ensured in developing countries. Thus it is significant to effectively reduce greenhouse gas emissions in developing countries.

The score of Scenario 2 is higher than Scenario 3, although developing countries adopt the complete or the partial sector-based approaches in both scenarios. This is mainly because reliability on data acquisition is lower in the complete than in the partial sector-based approach.

Scenario 2, in which developed countries adopt national numerical targets and developing countries adopt partial sector-based approach with flexibility measures, has the highest score. The reason is as follows. At first, acceptability of partial sector-based approach is higher than national numerical targets for developing countries. Second, certainty of reducing greenhouse gases is high, since developed countries adopt national numerical targets. The likelihood of

Scenario 2 by our methodology was also shown to be considerably high in the last chapter. In short, this framework deserves exploration both from likelihood and from evaluation.

5. Conclusion

In this paper, we first proposed the methodology combining the cross-impact method and Bayesian inference to project what type of institution will be adopted as post-Kyoto frameworks. Namely, we utilized Bayesian inference to introduce influences of significant international events into expert judgments, in which probabilistic consistency was maximized by the cross-impact method. Computed results by this methodology identified the several frameworks as post-Kyoto candidates with high probabilities. In the four among six scenarios, the complete or the partial sector-based approaches are adopted in industrialized or developing countries.

Then we evaluated the candidates for post-Kyoto frameworks. For this purpose, analytic hierarchy process is applied, taking account of reduction of greenhouse gases, economic impact, possibility of making consensus, and initiative in global negotiation. The evaluated result indicated that the framework has the highest score, in which industrialized and developing countries adopt national numerical target and partial sector-based approaches, respectively. This framework was concluded to deserve exploration both from the projection and the evaluation in this paper.

Even if the national numerical targets are imposed as the post-Kyoto framework, we can apply the sector-based bottom-up approach to set rational numerical targets. Furthermore, developing countries without any numerical targets in Kyoto Protocol would be able to play a significant role in the post-Kyoto framework by adopting sector-based approaches. Namely, sector-based approaches could bring about more reduction of greenhouse gases in developing countries than in the first commitment period. We concluded that sector-based approaches with wide institutional variations are effective for both industrialized and developing countries.

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