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Two-stage concession game approach for analyzing greenhouse gases emission reduction schemes

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ABSTRACT

Climate change imposes a huge treat on the sustainability of our environment. One of the major reasons for the increasing impacts of climate change is the emission of greenhouse gases. Therefore, cooperative greenhouse gas emission reduction schemes with a general consensus are needed in order to reduce the impacts of climate change. Due to the strong link between greenhouse gas emission and economic development there is disagreement among countries on the designing and implementation of emission reduction plans. In this paper the authors proposed a two-stage concession game to analyze emission reduction plans and determine a balanced emission range that improves the utilities of the bargaining parties. Furthermore the game was applied to a hypothetical example. Our results from the case study indicated that even though the utilities of the bargaining parties is highly affected by emission reductions, after making concessions their utilities can be improved given their emission reductions are within in a certain desirable range. The authors hope that this article provides insights which could be useful for understanding emission reduction plans and their consequences on the negotiating parties.

Keywords: Concession game, Cooperation, Game theory, Greenhouse gas, Pareto improvement

1. Introduction

Climate change which is mainly due to increasing greenhouse gases (GHG) emission is causing ozone depletion, rising temperatures, melting glaciers, and rising sea levels [1-3]. The relationship between fossil fuel consumption and subsequent GHG emission as well as the impacts GHG emission is having on the global climate has been researched extensively. Hence, it is generally agreed that in order to ensure the sustainability of the environment reducing the emission of GHG is needed and it is one of the key course of actions to minimize the negative impacts of climate change.

In recent years environmental problems due to climate change attracted the attention of governments, non-governmental organizations and researchers. At the international and national level efforts are undergoing to mitigate the impacts of climate change.

There is huge pressure on the developed and developing countries to reduce their GHG emission mainly from non-governmental organizations, environmental activists and researchers. Most of the developed countries are concerned that measures to reduce GHG could harm their economies. While the developing countries also fear that GHG emission reduction measures might slow down their rapid economic development. In addition the developing countries are putting the blame on the developed countries for the current deterioration of environmental quality and are stating that they have the right to promote their economic development. Therefore, even though studies showed and predicted the significant impacts climate change could have on the environment, the differences between the developed and developing countries on how to allocate emission rights and responsibilities is hindering the implementation of emission reduction plans like the Copenhagen Accord [4-5].

As it is sated above GHG emission reduction is one of the main measures that should be taken in order to abate the negative impacts of climate change. But reducing emission can have major impacts on economic development too. Hence when it comes to defining, responsibilities, obligations and adjusting interests, states

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often engage in political game. This is mainly because there is no enforcing authority and the countries have strong desire to maximize their economic benefits [6]. Such a scenario leads to “prisoner’s dilemma” situation there by causing environmental pollution. Therefore, finding the right compromise between the GHG emission reduction and economic development is crucial. How much should the emission reduction of each country be? The answer for this and other important questions concerning the emission reduction are still a bone of contention among the countries. The most important reason for the lack of agreed upon emission reduction schemes is the asymmetry that exists among the countries in terms of their socio-economic and environmental status. Therefore finding emission reduction scheme which caters to every country’s needs is very challenging.

Nowadays, researchers are using different methods and theories in order to design emission reduction plans with a general agreement. Some researchers formulated emission rights and analyzed the problem as an issue of property rights using the Coase theorem [7-10]. They used the concept of “pollution rights” and tried to solve the problem through negotiation. But it is hard to build stable cooperation among the negotiating parties, since there are differences between the actual market structure and ideal market structure [11].

Optimization methods can be used to find the values for workable scenarios for various problems other than GHG emission reduction, for instance [12-18]. Game theoretic optimization solutions are one of the analytical methods that can be applied to solve GHG emission reduction problems. In order to ensure fair and stable cooperation, scholars are using game theory to analyze negotiation and cooperation efforts for GHG emission reduction [19-28]. These papers are highly focused on analyzing the relationship between different countries rather than analyzing the impacts of emission reduction on their utilities. Therefore, a methodology that analyzes the impacts of greenhouse gas emission reduction on the utilities of the negotiating countries could provide strategic information which might be useful for building sustainable cooperation among the countries. In this article assuming that countries will take measures to reduce the impacts of climate change and among these measures greenhouse gas emission reduction being the main one, the authors established a game theoretical model to analyze the main policy choices of bargaining parties during GHG emission reduction negotiations. Furthermore, the game theoretical model was applied to a two agent hypothetical case study and then the balanced emission reduction range which is pareto-improving for the negotiating parties was determined.

The rest of the article is organized as follows. The second section describes the concession game model parameters and rules. The third part analyzes and discusses the concession game. The fourth section presents and discusses the results obtained by applying the model to a hypothetical example proposed in this article. The fifth part summarizes and concludes the paper.

2. Methods

In this part of the article the authors put forward the rules and assumptions that are used in the rest of the article. In order to simulate the ongoing international negotiations for GHG emission reduction from here on the term “coalition” will be used to refer to the negotiating parties. The game is divided into two stages. In the first stage$(t=0)$ the two coalitions negotiate to make concessions. In the second stage $(t=1)$ concessions to reduce GHG emission are realized. Such approach converts the static concession game in to a dynamic one. At the end of the concession both coalitions are expected to reduce their status quo emission levels.

Both coalitions will take in to account their interests that will be affected by implementing emission reductions and their economy is the main one.

$$R_i(^1_i, e_i^{2n}, \cdots, e_i^n, R_j) = R_j(e_j^1, e_j^2, \cdots, e_j^n, R_i) \tag{1}$$

$R_i(\bullet)$ and $R_j(\bullet)$ are reduction functions for the two coalitions (i, j), $e_i^1, e_i^2, \cdots, e_i^n$ and $e_j^1, e_j^2, \cdots, e_j^n$ are emission reduction decision variables. The coalitions’ emission reductions are dependent on their emission reduction decision variables and each other’s emission reductions.

Suppose $R_i(\bullet)$ / $R_j(\bullet)=w_j$. Where w_j is the concession of coalition j relative to coalition i. This approach helps to protect the interests of the negotiating coalitions and avoid the cost associated with taking too much time to reach a compromising decision on emission reduction. Now suppose that the two coalitions carried out concessions based on their negotiation strategy. $s_i^1 \in [0, x_i^0]$ is the amount of emission reduction coalition i made at $t=1$ based on its status quo emission variable x_i^0. The Nash equilibrium decision value for coalition i at $t=0$ is x_i^0. The respective emission reduction for coalition j is $w_j x_i^0$. If coalition i reduce $x_i^0$the same applies for coalition i who is involved in the emission reduction game with coalition j.Hence, the following equality is satisfied.

$$s_i^1 = \begin{cases} x_i^0,\ w_i s_j^1 \geq x_i^0 \\ w_i s_j^1,\ w_i s_j^1 < x_i^0 \end{cases} \tag{2}$$

Eq. (2) represents the amount of reduction each coalition makes during $t=0$. Eq. (2) also shows that each coalition has s_i^1 and w_i as decision variables. Winner or loser in the negotiation process is determined by the bargaining power of the negotiating parties.

At $t=1$ the rule to judge the winner and the loser in the negotiation process is marked out as follows;

$$\frac{w_i s_j^1 \big/ x_i^0}{s_i^1 \big/ x_j^0} > \frac{w_j s_i^1 \big/ x_j^0}{s_i^1 \big/ x_i^0} \tag{3}$$

Simplifying Eq. (3) leads to;

$$w_i \frac{x_j^0}{x_i^0} > w_j \frac{x_i^0}{x_j^0} \Rightarrow w_i > w_j \left(\frac{x_i^0}{x_j^0} \right)^2 \tag{4}$$

Since $M=\left(\frac{x_i^0}{x_j^0}\right)^2$ Eq. (4) can be further simplified to;

$$w_i > Mw_j \tag{5}$$

If $w_i > Mw_j$ then coalition i is the winner at $t=1$ and bids a greater proportion of concession than the relative concession decision variables of the loser which is j. On the other hand if $w_j > Mw_i$ then coalition j is the winner at $t=1$ and bids a greater proportion of concession than the relative concession decision variables of the loser which in this case is coalition i .When both sides of Eq. (5) are equal random way is used to determine the winner and the loser [29].

Assuming the two coalitions will make the appropriate concessions and coalition i is the winner and w_i is its corresponding offer, then as loser coalition j makes a concession first. Its concession which is the function of w_i will be $s_j(w_i)$. Therefore utility function of coalition j will be;

$$y_j^L(w_i) = u_j(x_i^0 - w_i s_j(w_i),\, x_j^0 - s_j(w_i)) \tag{6}$$

The utility function of coalition i as winner is can be written as;

$$y_i^W(w_i) = u_i(x_i^0 - w_i s_j(w_i),\, x_j^0 - s_j(w_i)) \tag{7}$$

Since the game is being played under incomplete information, the utility improvement coalitions receive as a winner or a loser is the same.

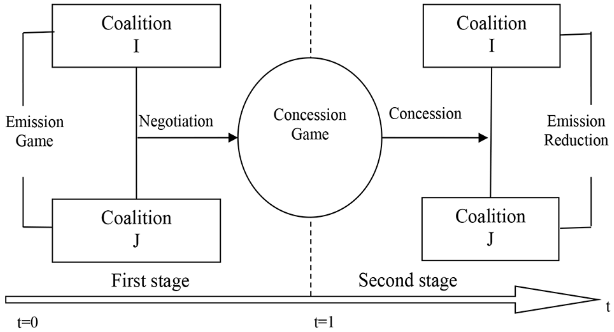

Fig. 1. Two-stage concession game for global GHG emission reduction.

3. Results and Discussion

The GHG emission levels of coalitions differ depending on the economic, social, demographic and many other additional factors which are not mentioned here. Assuming the coalitions are risk neutral the utility functions in relation to GHG emission can be described using the Environmental Kuznets Curve [30, 31] and Lotka-Volterra model [32].

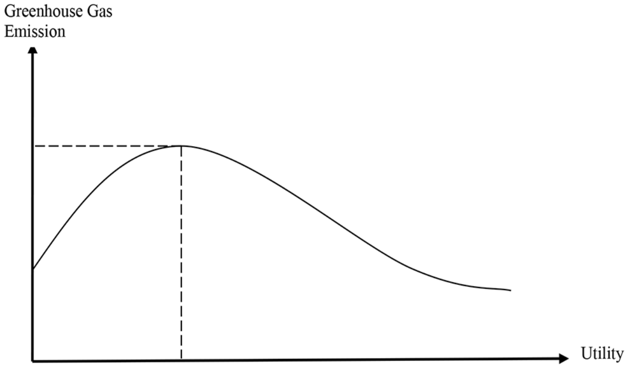

Fig. 2. Environmental Kuznets Curve (EKC) for global GHG emission.

Assuming the utility function of the negotiating parties are the following;

$$\begin{cases} y_i^0 = a_i x_i^0 - b_i (x_i^0)^2 - b_i x_i^0 x_j^0 \\ y_i^0 = a_j x_j^0 - b_j * s_j^0)^2 - b_j x_i^0 x_j^0 \end{cases} \tag{8}$$

$a_i > 0$ is the logistic coefficient showing the economic benefits.The emissions of one coalition have negative environmental and economic externalities on the other coalition. One's utility function is a decreasing function of other's GHG emission. Therefore $b_i > 0$ is the constraining parameter. According to the law of diminishing marginal utility the graph of utility function of each negotiating agent is concave.

Maximizing the utility functions of countries mentioned in Eq. (8) leads to the following two response functions:

$$\begin{cases} \dfrac{dy_i^0}{dx_i^0} = a_i - 2b_i x_i^0 - b_i x_j^0 \\ \dfrac{dy_j^0}{dx_j^0} = a_j - 2b_j x_j^0 - b_j x_i^0 \end{cases} \tag{9}$$

Because $\frac{d^2 y_i^0}{d^2 x_i^0} < 0$, $\frac{d^2 y_j^0}{d^2 x_j^0} < 0$ the decision variables which make Eq. (9) zero can be described as Nash equilibrium values.

$$\begin{cases} x_i^0 = \dfrac{2a_i b_j - a_j b_i}{3b_i b_j} \\ x_j^0 = \dfrac{2a_j b_i - a_i b_j}{3b_i b_j} \end{cases} \tag{10}$$

Hence;

$$2a_i b_i - a_j b_i \geq 0 \text{ and } 2a_j b_i - a_i b_j - a_i b_j \geq 0$$

$$\begin{cases} y_i^0 = \dfrac{(2a_i b_j - a_j b_i)^2}{9b_i (b_j)^2} \\ h_j^0 = \dfrac{(2a_j b_j - a_i b_j)^2}{9(b_i)^2 b_j} \end{cases} \tag{11}$$

According to the designed concession rules assuming coalition i is the winner during the negotiation process coalition j as the loser cuts its status quo GHG emission first and its utility function will be;

$$y_i^{1L} = a_j(x_j^0 - s_j) - b_j(x_j^0 - s_j) - b_j(x_i^0 - w_i s_j)(x_j^0 - s_j) \quad (12)$$

Differentiating Eq. (12) by equating it to zero results the following emission reduction decision variables for coalition j

$$x_j(w_i) = S'(w_i) = \frac{w_i(2a_j b_i - a_i b_j)}{6b_i b_j(w_i + 1)} \quad (13)$$

$$x_j^1 = x_j^0 - S' = \frac{(w_i + 2)(2a_j b_i - a_i b_j)}{6b_i b_j(w_i + 1)} \quad (14)$$

Then the corresponding emission reduction variables of coalition i will be;

$$s_i(s_j) = w_i S' = \frac{(w_i)^2(2a_j b_i - a_i b_j)}{6b_i b_j(w_i + 1)} \quad (15)$$

$$x_i^1 = x_i^0 - w_i S' = \frac{2(2a_1 b_2 - a_2 b_{1)(w_i} + 1)}{6b_i b_j(w_i + 1)} - \frac{(w_i)^2(2a_j b_i - a_i b_j)}{6b_i b_j(w_i + 1)} \quad (16)$$

The utility functions of the negotiating parties can be formulated as follows;

$$\begin{cases} y_i^{1W} = (a_i - b_i(x_j^0 - s_j))(x_i^0 - w_i s_j) - b_i(x_i^0 - w_i s_j)^2 \\ y_j^{2L} = n(a_j - b_j(x_i^0 - s_j) - b_j(x_j^0 - s_j)^2 \end{cases} \quad (17)$$

On the other hand when coalition j is assumed to be the winner its emission reduction functions will be the following;

$$\begin{cases} s_i^n = \dfrac{W_j(2a_i b_j - a_j b_i)}{6b_i b_j(w_i + 1)} \\ s_j^n(s_i^n) = \dfrac{(w_j)^2(2a_i b_j - a_j b_i)}{2b_i b_j(w_j + 1)} \end{cases} \quad (18)$$

The corresponding utility functions of the bargaining coalitions can be written as;

$$\begin{cases} y_i^{1L} = (a_i - b_i(x_i^0 - w_j s_i^{nn})(x_i^0 - s_i^n) - b_i(x_i^0 - s_i^n)^2 \\ y_j^{2W} = (a_j - b_j(x_i^0 - s_i^n))(x_j^0 - w_j s_i^n) - b_j(x_j^0 - w_j s_i^n)^2 \end{cases} \quad (19)$$

Based on the assumptions made above the optimal strategy is the one that ensures the same utility improvements to bargaining coalitions irrespective of whether they are winners and losers of negotiation process. Hence the dominant strategy is the one that satisfies $y_i^{1W}(w_i) = y_i^{1L}(w_j)$. Based on the rules of concessions defined in section two of this paper coalition i 's bid w_i have equal preference with coalition j 's bid $w_j = \frac{w_i}{M}$ during negotiations. Therefore, coalition i choose the optimal strategy that ensures $y_i^{1W}(w_{i)} = y_i^{1L}(w_i/M)$ thus;

$$\begin{cases} w_i = W_i(a_1, a_2, b_3, b_4) > 0 \\ w_j = W_j(a_i, a_2, b_3, b_4) > 0 \end{cases} \quad (20)$$

Assuming both the negotiating parties will implement the optimal strategy, if $W_i > MW_j$ coalition i will be the winner and coalition j the loser otherwise i will be loser and coalition j will be the winner. When coalition i is the winner and coalition j the loser their respective GHG emission reductions will be $w_i S'$ and S' respectively. In this case their utility functions will be;

$$\begin{cases} y_i^{1W} = (a_i - b_i(x_j^0 - S'))(x_i^0 - w_i S') - b_i(x_i^0 - w_i S')^2 \\ y_j^{2L} = (a_j - b_j(x_i^0 - w_i S'))(x_j^0 - S') - b_j(x_j^0 - S1')^2 \end{cases} \quad (21)$$

Hence, $\triangle y_i^{1W} = y_i^{1W} - y_i^0$ and $\triangle y_i^{2L} = y_j^{2L} - y_j^0$

$$\triangle y_i^{1W} = \frac{(a_i b_j((w_i)^2 + 4)(2a_j n_i - a_i 1 b_j)}{36(w_i + 1)b_i(b_j)^2} - \frac{2a_j b_i((w_i)^2 + 1)(2a_j b_i - a_i b_j)}{36(w_i + 1)b_i(b_j)^2} \quad (22)$$

$$\triangle y_j^{2L} = \frac{(w_i + 1)^2(2a_j b_i - a_i b_j)^2}{36(w_i + 1)(b_i)^2 b_j} \quad (23)$$

Therefore, $\triangle y_j^{2L} \geq 0$

After making concessions at the end of the game both the bargaining parties reduce their status quo emission levels. The degree of utility improvement for coalition i depends on its logistic and constraint parameters as well as on the utility improvement of coalition j. The converse is also true when coalition j is a winner.

When $MW_j < W_i < 2\sqrt{\frac{2a_i b_j - a_j b_i)}{2(2a_j b_i - a_i b_j)}}$ coalition i as a winner of the negotiation will improve its utility. If $W_i < 2\sqrt{\frac{2a_i b_j - a_j b_i)}{2(2a_j b_i - a_i b_j)}}$ the utility of coalition i will decrease. Since the game is symmetric when coalition j is winner even though coalition i is loser its utility improvement is similar to its utility improvement it can secure as a winner. From the above analysis the following conclusions can be reached. First, the utilities of both the bargaining parties will not improve during the first stage of the negotiation process. During, the second phase of negations because both parties makes reductions in emissions their utilities improve. The utility of coalition j improves since it is the loser in the negotiation process while the utility of coalition i will improve as well as long as it is with in the balanced emission range. Generally winners have high GHG emission reduction ratios. Second, if the two coalitions act unilaterally to maximize their benefits they may not achieve pareto-optimality and end up with "tragedy of the commons" scenario. The negotiating coalitions cannot achieve pareto-optimality by making concessions as well, but if their GHG emission reductions are within a certain balanced range both the negotiating parties can achieve pareto-improvement.

4. Hypothetical Example

Suppose there are two coalitions i and j. The two coalitions emit GHG mainly due to consumption of fossil fuels. Emission of GHG has negative environmental consequences. The two coalitions acknowledge the problem and are willing to reduce GHG emissions through negotiations. Therefore concession game can be used to analyze their emission reduction plans and determine the balanced emission range that results in utility improvement for both negotiating coalitions. The utility functions of the bargaining coalitions can be written as the following;

$$\begin{cases} y_i^0 = 3x_i^0 - 2(x_i^0) - 2x_i^0 x_j^0 \\ y_j^0 = 4x_j^0 - 3(x_j^0) - 3x_i^0 x_j^0 \end{cases}$$

At $t = 0$ maximizing the above utility functions results the following values for the emissions and utilities of the negotiating coalitions.

$$\begin{cases} x_i^0 = 0.5556 \\ x_j^0 = 0.3889 \end{cases} \qquad \begin{cases} y_i^0 = 0.6173 \\ y_j^0 = 0.4537 \end{cases}$$

Now suppose that coalition i is the winner and coalition j is loser. If coalition j reduces emissions by a unit then coalition i should reduce by w_i units. Therefore, the utility function of coalition j will be;

$$y_j^{1L} = \left(4 - 3\left(\frac{5}{9} - w_i s_j\right)\right)\left(\frac{7}{18} - S_j\right) - 3\left(\frac{7}{18} - s_j\right)^2$$

Since $\frac{dy_j^{1L}}{ds_j} = 0$, rearranging the above equation leads to the following reduction functions for the coalition i and j.

$$\begin{cases} s_i = \dfrac{7(w_i)^2}{36 + 36w_i} \\ s_j = \dfrac{7w_i}{36 + 36w_i} \end{cases}$$

Therefore the utilities of the coalitions can be formulated as the following;

$$\begin{cases} y_i^{1W}(w_i) = \left(3 - 2\left(\dfrac{7}{18} - \dfrac{7w_i}{36 + 36w_i}\right)\right)\left(\dfrac{5}{9} - \dfrac{7(w_i)^2}{36 + 36w_i}\right) \\ \qquad - 2\left(\dfrac{5}{9} - \dfrac{7(w_i)^2}{36 + 36w_i}\right)^2 \\ y_j^{1L}(W_L) = \left(4 - 3\left(\dfrac{5}{9} - \dfrac{7(w_i)^2}{36 + 36w_i}\right)\right)\left(\dfrac{7}{18} - \dfrac{7w_i}{36 + 36w_i}\right) \\ \qquad - 3\left(\dfrac{7}{18} - \dfrac{7w_i}{36 + 36w_i}\right)^2 \end{cases}$$

Similarly, if coalition j is winner and coalition i is loser their emission reduction functions of the coalitions will be;

$$\begin{cases} \overline{s}_i = \dfrac{10w_j}{36 + 36w_j} \\ \overline{s}_j = \dfrac{10(w_j)^2}{36 + 36w_j} \end{cases}$$

Hence the corresponding utility functions of the coalitions' becomes;

$$\begin{cases} y_i^{1L}(w_j) = \left(3 - 2\left(\dfrac{7}{18} - \dfrac{10(w_j)^2}{36 + 36w_i}\right)\right)\left(\dfrac{5}{9} - \dfrac{10w_j}{36 + 36w_j}\right) \\ \qquad - 2\left(\dfrac{56}{9} - \dfrac{10w_j}{36 + 36w_j}\right)^2 \\ y_j^{1W}(w_j) = \left(4 - 3\left(\dfrac{5}{9} - \dfrac{10w_j}{36 + 36w_j}\right)\right)\left(\dfrac{7}{18} - \dfrac{10(w_j)^2}{36 + 36w_i}\right) \\ \qquad - 3\left(\dfrac{7}{18} - 10(w_j\dfrac{)^2}{36 + 36w_i}\right) \end{cases}$$

Hence;

$$\begin{cases} M = \left(\dfrac{x_i^0}{x_j^0}\right)^2 = 2.0410 \\ M' = \left(\dfrac{x_j^0}{x_i^0}\right)^2 = 0.4899 \end{cases}$$

Coalition i's bid w_i and coalition j's bid w_j are the keys to determine the winner and the loser in the negotiation process. Weather the coalition is winner or a loser it gains the same utility improvement.

When $y_i^{1W}(w_i) = y_i^{1L}(0.4899w_i)$ then w_i is equal to 1.3780 and When $y_j^{1W}(w_j) = y_2^{1L}(2.0410w_j)$ $w_j$is equal to 0.2494. Therefore for the case $w_i > 2.0410w_j$ coalition i is the winner and coalition j is the loser. Their respective reductions s_j and s_i will be 0.1127 and 0.1533. Hence at the end of the concession the condition $MW_j < W_i < 2\sqrt{\frac{(2a_i b_j - a_j b_i)}{2(2a_j b_i - a_i b_j)}}$ is satisfied. This indicates that the utilities of the two bargaining coalitions are improved. The emission levels after reduction and utilities of the negotiating coalitions will be;

$$\begin{cases} x_i^1 = 0.5003 \\ x_j^1 = 0.2762 \end{cases} \qquad \begin{cases} y_i^1 = 0.6593 \\ y_j^1 = 0.5442 \end{cases}$$

5. Conclusions

GHG emission is one of the main contributing factors for climate change. Hence coordination and cooperation among the countries are needed in order to reduce GHG emission and minimize the impacts of climate change. One of the main reasons that makes global GHG emission reduction challenging is the differences among the countries in terms of their socio-economic and environmental status. Therefore emission reduction plan should cater to the principle of common but differentiated responsibilities of the different countries. Concession game is proposed in this article as a tool to analyze the reduction schemes and determine the emission range which will improve the utilities of the negotiating parties. Since both the negotiating parties are utility maximizes and risk neutral authors believe that the concession approach to analyze emission reduction plan is a reasonable approach.

Both bargaining parties look for a solution outcome which will improve their utilities. But if they act independently the utility each of them can achieve is less than the utility they can achieve by coordinating their emission policies [33]. The advantages negotiating parties can gain from unilateral actions in the short term are lower than the long term benefits that can be obtained from cooperation. In addition, the benefits that can be obtained from repeated short term games become negligible through time. This is one reason that drives the parties to cooperate through concession game so as to achieve the desired maximum benefit through cooperation [34]. This article discusses non-transferable utility concession game's application for analyzing emission reduction plan and determining the stable emission reduction range that improves the utilities of the negotiating parties. From the above analysis the authors were able to deduce the following two main conclusions. First, the reductions will affect each agent's utility in the game and changes in utility depend on logistic and constraining parameters. Second, even though the negotiating parties may not be able to achieve pareto-optimality by reducing emissions each negotiating party will be able improve its utility. After the concessions the loser of negotiation process achieves improvement in its utility. The winner enhances its utility as well. Hence the concession procedure results in a win-win situation for both the negotiating parties. One of the main shortcomings of this study is that it did not take in to account strategies to reduce uncertainties. This limitation is left to be addressed through further research. Generally, the authors hope that this article provides insights which could be useful for policy makers in their effort to design implementable emission reduction plans.

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Nomenclature

Symbol	Definition
i, j	Coalitions
t	The time period of emission the reduction game
$t=0$	First stage of emission reduction game, before negotiation
$t=1$	Second stage of emission reduction game, after negotiation
$R_i(\bullet),\ R_j(\bullet)$	Reduction functions of negotiating coalitions
$e_i^1, e_i^2, \cdots, e_i^n$	emission reduction decision variables
w_i, w_j	The relative emission reduction of different coalitions
x_i^0, x_j^0	The status quo emission levels of the different coalitions during $t=0$
x_i^1, x_j^1	The emission reduction decision variable of different coalitions during $t=1$
s_i^1, s_j^1	Emission reductions of different coalitions at second stage $t=1$
y_j^L	Utility of coalition j as a loser in negotiation
y_i^W	Utility of coalition i as a winner in negotiation
y_j^{1W}	Utility of coalition j as a winner in negotiation
y_j^{1L}	Utility of coalition j as a loser at second stage
y_i^{1W}	Utility of coalition i as a winner in negotiation
y_i^{1L}	Utility of coalition i as a loser in negotiation
$y_i^0,\ y_j^0$	Utilities of bargaining coalitions at first stage
a_i, a_j	Logistic coefficients of utility functions
b_i, b_j	Constraining parameters of utility functions
$s_j(w_i)$	Emission reduction of coalition j as a loser at $t=1$
$S'(w_i)$	Emission reduction function of coalition j as a loser at $t=1$
$s_i(s_j)$	Emission reduction of coalition i as a winner at $t=1$
s_i''	Emission reduction of coalition i as a loser at $t=1$
$s_j''(s_i'')$	Emission reduction of coalition j as a winner at $t=1$
$\triangle y_i^{1W}, \triangle y_j^{1L}$	The utility changes of coalitions between two stage
$W_i(a_{1,} a_2, b_{3,} b_4)$	Bid function of coalitions i
$W_j(a_1, a_2, b_3, b_{r)}$	Bid function of coalitions j

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