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# CYBERNETIC PARADIGM BASED INNOVATIVE APPROACHES TOWARDS COPING WITH CLIMATE CHANGE

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**Abstract**

Increasing carbon emissions from large-scale human activities have contributed to global climate change, which has resulted in an increase in significant human crises. Therefore, as carbon abatement is a public good, coping with climate change is also a public-good; however, it suffers from many free-rider incentives, leading to a tragedy of the commons. Overcoming this challenge from a systemic perspective, requires that all sectors such as industry, government, and citizens on global, national, and regional levels engage in low-carbon development and the implementation of fair and efficient climate policies. Through a theoretical exploration of carbon abatement and a systemic description of low-carbon systems, this paper developed a cybernetic framework for coping with climate change, which consists of a cloud platform for data analysis, meta-synthetic engineering for decision support, a polycentric approach to extensive consultation and various functional goal achievement modules. On this basis, by combining the "invisible hand" and "visible hand" and by integrating negotiation at the global level, cooperation at the national level and knowledge at the local level, a multilevel policymaking model is proposed to address complex climate change problems. This cybernetic paradigm based innovative approach could provide valuable illumination to stakeholders seeking to cope with climate change.

**Keywords:** Cybernetics, climate change, carbon abatement, public good, low-carbon development

## 1. Introduction

Climate change, which is a result of increasing carbon emissions from large-scale human activities, has caused significant environmental and humanitarian crises (Easterling 2000, Patz 2005, Urban 2015). If anthropogenic carbon emissions are allowed to increase without the imposition of appropriate restrictions, climate change is expected to further destroy the environment, seriously threatening not only human existence but all life on earth. Reducing carbon emissions in all areas and adapting economies and societies to climate change are the only sustainable solutions. In this context, three international treaties were widely discussed and approved in succession as milestones for global action on climate change; specifically, the United Nations Framework Convention on Climate Change (UNFCCC), as the cornerstone, passed in 1992, The Kyoto Protocol, as the legal rule, passed in 1997 and The Bali Road Map, as the action guideline, passed in 2007. Besides these treaties, the Intergovernmental Panel on Climate Change (IPCC) published assessment reports in 1990, 1995, 2001, 2007, and 2014, calling on policymakers and citizens to tackle this overwhelming challenge. Yet there is still no effective regime for carbon emissions reduction and climate change adaptation (Geden 2015).

Tackling climate change is a complex systems engineering problem. The preamble to the UNFCCC affirmed that “responses to climate change should be coordinated with social and economic development in an integrated manner with a view to avoiding adverse impacts on the latter, taking into full account the legitimate priority needs of developing countries for the achievement of sustained economic growth and the eradication of poverty”. Likewise, the IPCC (2007) highlighted that development needed to be more sustainable and by changing our development paths, significant contribution could be made to climate goals. Simply put, we need to find a path that allows for both a rapid growth in regional economies and sharp reductions in carbon emissions. However, the interaction between climate change and economic development leads to a paradox: economic development can accelerate climate change, which in turn can block further development (Jorgenson 2014). Against this backdrop, low-carbon development (LCD), an ecological economic development paradigm for balancing and harmonizing economic development, emissions reduction and environmental protection, has been proposed and widely adopted as an alternative pathway (Mulugetta and Urban 2010, Cranston and Hammond 2010).

Not only is climate change a common global challenge, it is also an opportunity to expand sustainable development research. To concurrently reach the seemingly contradictory goals of carbon abatement and economic growth, the LCD pathway depends on the innovation and utilization of knowledge-based, integrated approaches. Thompson et al. (2014) linked three advanced models to present a systems approach to quantify the air quality co-benefits of US carbon policies in reducing carbon emissions. Gracceva and Zeniewski (2014) proposed a novel framework and developed a complex multi-regional energy system model for a low-carbon EU energy system to systematically explore the synergies and trade-offs between climate change policies and energy security. Geels et al. (2016) bridged three model-based analytical approaches to support climate policy making for low-carbon transitions. Trumpy et al. (2016) set up a systematic approach for potential geothermal assessment and applied it in Southern Italy to develop a low-carbon strategy and establish low-carbon policies.

Many systematic approaches have been developed to address various aspects of low-carbon development and some problems have been effectively solved. This paper follows the cybernetic approach because of the feedback relationship between humanity and the climate which reflects the belief that human actions are changing the climate while at the same time the climate is changing human actions. People are not outside observers of global climate change but rather are inside the climate system that is being changed. If cybernetics is the science of organized complexity, feedback, therefore, is the science of cybernetics. Because of this feedback mechanism, we developed cybernetic based approaches for coping with climate change.

Cybernetics is a trans-disciplinary approach for the exploration of structures and constraints and the possibilities of complex systems by using ideas such as feedback, circularity and information (Wiener 1948). While a system deals with the structure, cybernetics deals with the way the structure operates (Clemson 1984). To solve complex climate system problems, the Analytic Paradigm, which is based on abstract models, creates an information overload for decision-makers, but cannot guarantee improved decision-making. The Cybernetic Paradigm, on the contrary, which integrates qualitative and quantitative modeling and expert knowledge based systems, is a human-based paradigm more appropriate for group decisions in goal-directed, functional systems (Heylighen and Joslyn 2003). Through a theoretical exploration of carbon abatement and a systemic description of the LCD system, this paper proposes a cybernetic framework and a policymaking model to understand and address the complex problems of climate change.

## 2. Theoretical Exploration

As carbon abatement is a global public good, reducing carbon emissions is a global public-good game (Sandler 2004, Rand and Nowak 2009). Public goods were recognized by Adam Smith and Paul Samuelson as an important part of the societal fabric. In particular, each person's carbon emissions cumulatively contribute to global concentrations; therefore, no single individual, agency, or a nation can unilaterally solve this challenge. Prof. Ostrom (2014), who won the 2009 Nobel Prize in Economic Sciences, argued that single policies adopted only at a global scale are unlikely to generate sufficient trust in citizens and firms for effective collective action towards coping with climate change. The climate change crisis is the largest current public-goods dilemma and one of the biggest tragedies so urgently needs global collective action to be solved.

### 2.1 A Public Choice View

Climate change is a typical tragedy of the commons on a global scale (Hardin 1968, Milinski et al. 2002). The "tragedy of the commons" refers to a situation in which individuals rationally act in their own interests, but irrationally exhaust commonly owned resources as a whole. It is therefore a puzzle to many observers that rational actions separately conducted by individuals that accelerate development often do not consider carbon abatement, so ultimately lead to irrational outcomes such as the increase in extreme weather events around the world. As these issues are of great concern, the theory of public choice could be a promising point of view.

Public choice theory proposes that climate change is the cumulative consequence of everyone's carbon emissions behavior, but its pernicious consequences are shared equally by all participants. Each individual acts for their own advantage and benefit, while the costs of those actions are spread across the general public. The public-good nature of climate efforts gives rise to an ineffective choice of reduction instruments and to an inefficient attainment of the set goals (Dietz et al. 2003). For instance, the Kyoto Protocol sets an initial international commitment for quantified limits on carbon emissions and exerts pressure on contracting parties to reduce carbon emissions (Boyd and Ibarrarán 2002). However, the United States, the world's largest carbon emitter at that time, did not initially join the Kyoto Protocol and Canada, New Zealand, Russia, and Japan sequentially withdrew before the second commitment period. Each country is only a small part of the global economy and contributes only a small percentage of global carbon emissions; however, the "rational" choice of some countries, which is based on a self-serving consideration of the national interest, results in unsuitable outcomes when addressing global carbon abatement issues.

## 2.2 The Game Theoretic Perspective

The structure of the commons tragedy is consistent with that of a prisoner's dilemma, in that the persistent tension between national self-interest and global common-benefit is a main feature of climate-related decision processes. Further, the prisoners' dilemma is a good illustration of the game between developing countries and developed countries. As stipulated in the UNFCCC, developing countries are not required to reduce emissions levels unless developed countries supply adequate funding and technology. Facing increasingly serious climate challenges, developing countries claim that the developed world should undertake the main task of reducing emissions and fulfill their responsibility of financial assistance and technology transfer. Developed countries, on the contrary, demand that the large developing countries and emerging economies, which have been contributing significantly to increasing carbon emissions, should also curb their emissions within certain limits. The game theoretic perspective, therefore, is pessimistic about the success of international collective action in relation to global climate change, as self-enforcing agreements are unlikely because of free-rider incentives.

To promote compliance with climate agreements, game theory suggests that rigorous rules and strong enforcement are required to maintain stable equilibrium. In this regard, an alternative to the commons does not need to be perfect, just preferable. A socially optimal outcome could be achieved if most of those involved cooperated by selecting strategies other than those prescribed by the Nash equilibrium. Game theory therefore gives logical force to Hardin's expectation of noncooperation and leads to a socially sub-optimal choice for climate change issues. As the joint outcome is sub-optimal, no party is independently motivated to change their choice, given the predictable choices that others will make. Moreover, to avoid transgression, such as those outlined in the Kyoto Protocol, punishments ought to be individually and collectively rational, so need to operate on the Pareto frontier, rather than in other sub-optimal states.

## 2.3 The Assigning of Property Rights

Complete freedom leads to tragedy (Hardin 1998). One approach to ending the tragedy of the commons was devised some 50 years ago by Ronald Coase. His solution was to assign property rights so as to share the carbon emissions rights, and then to compensate the contributors from the emissions trading market. With private ownership established, the market mechanisms could increase the enthusiasm for emissions reduction (Coase 1960). Embodied in the Kyoto Protocol, three flexibility mechanisms; International Emissions Trading (IET), Clean Development Mechanism (CDM) and Joint Implementation (JI); were designed to coordinate the implementation of the allocation of and transactions in carbon emissions rights. Although there are still deficiencies in this model, a market is created to allow actors to buy and sell emissions permits according to their own needs. In theory, this approach should provide incentives to participants to engage in emissions reduction under seemingly fair trade rules. In practice, however, these types of deals are difficult to conclude and are often violated, both from a public choice and a game theoretic perspective.

Since reaching a binding agreement at international level has proven extremely difficult, it is worth considering some of the possible reasons for this failure. According to Coase's theory, one of the chief obstacles to the conclusion of these agreements has been the high transaction costs (Coase 1960). Given the complexity of the climate issues, high transaction costs are clearly an obstacle to international agreements. Such complexity is evident in the debate as to how best to distribute the responsibility given the developed countries' historical responsibility for the crisis, and the disagreements as to whether larger nations with forests should be allowed to discount these carbon sinks against their obligations to reduce emissions. According to Coase's hypothesis, if such transaction costs could be reduced, the probability of successful agreements would increase. From the cybernetics perspective, a reduction in transaction costs means an increase in communication and a reduction in entropy.

Unavoidably, there are strong free-rider incentives in international climate cooperation as well as weak political and economic instruments for attaining and maintaining the climate agreement goals. Similarly, it is quite difficult for governments to convince people to give up part of their current wealth for the sake of uncertain gains in the future, especially for those groups that have remained unaffected by climate disasters. The predicament, therefore, arises because of the difficulties in privatizing the benefits gained through individual sacrifices to prevent a climate tragedy. Therefore, it is time to seek a new solution. Low-carbon cybernetic based systematic approaches could be suitable in assisting this complex, crowded, changeable world cope with the global climate change crisis.

## 3. Systemic Description

To tackle climate change, formulate low-carbon policies and implement low-carbon strategies, the LCD system needs to be understood as an open complex giant system consisting of many parties and multiple driving forces. All sectors (e.g. government, industry, environmental organizations and local communities) at all levels (i.e. global, national, regional and local) must consider their decisions and choices to ensure the minimization of carbon emissions (Xu et al. 2014). The core concept of the LCD system is the reduction of carbon emissions and the gaining of greater economic, environmental and social benefits through technical innovation, industrial transformation, infrastructure redevelopment and energy structure optimization, based on the joint efforts of the whole society (Skea and Nishioka 2008). The structure of an LCD system is shown in Figure 1.

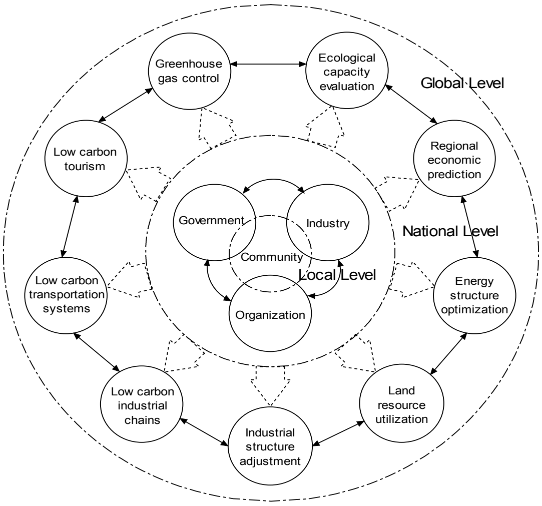


**Figure 1** The structure of a low-carbon system coping with climate change

## 3.1 Multiple Scales

As climate change has already deeply affected societies around the world at each level, LCD has to be acted across multiple global, national, regional and local layers. At the global level, there is a growing consensus to control atmospheric carbon concentrations below an appropriate level within a certain period for climate change mitigation. Legally-binding international agreements such as the recently passed Paris Agreement on Climate Change must therefore be reached and enforced at a global level while agreement must be reached on the international arena as to the specific level of emissions reduction required by each nation. If not supported by efforts at national, regional, and local levels, global solutions negotiated at a global level are not guaranteed to work well.

Further, as the old slogan "Think Globally but Act Locally" indicates, while many of the effects in response to climate change are global and the major decisions are made at the international level, the subsequent actions must be enforced by local people in every country and area. Ostrom (2009) argued that moderate territorial size is most conducive to self-organization. In this regard, regional and local LCD are unquestionably the basis and core of global and national LCD. Due to the closeness and access to civic society, the local level also encourages public consensus by raising the awareness of citizens and integrating the grassroots populations into decisions. Because the implementation of climate strategies relies heavily on local behavior and investment choices, success can only be assured when initiatives and activities are carried out at the local level.

## 3.2 Multiple Actors

There are many parties in the world involved in coping with climate change. Each party has their respective view on and definition of this crucial affair and have different problem solving goals. The key actors in the climate change arena are basically the government, industry, environmental organizations and local communities.

Governments play a primary role in pushing for carbon emissions reductions and low-carbon development. The United Nations, the largest intergovernmental organization, has been the dominant driver behind global climate change efforts through its establishment of the IPCC in 1988, the holding of annual global climate conferences since 1995 and the promotion of a series of international climate treaties. Politicians and bureaucrats have made the general public aware of the necessity and urgency of firmly addressing climate change. Policymakers also enable low-carbon industrial production and technological innovation by creating economic incentives and support mechanisms for green industry start-ups and energy conservation and through the creation of knowledge-sharing platforms.

The goal of industry is to keep the costs of coping with climate change as low as possible. However, without the participation of responsible companies, a low-carbon economy cannot take root. If low-carbon enterprises take the lead in economic development, there could be an organizational evolution in industries, a stimulation of the transmission and diffusion of low-carbon technologies between enterprises and the promotion of the overall development of a low-carbon economy.

The agenda of all climate-related environmental organizations is to urge the government, enterprises and individuals to reduce carbon emissions. Representing the overall rights and interests of the human race and the ecological environment, these organizations are playing increasingly important roles in promoting carbon reduction schemes. Community-based initiatives and public education campaigns led by environmental groups can influence individual behavioral choices to pursue a low-carbon lifestyle.

The poor consumption habits of communities also increase carbon emissions from coal power plant electricity generation and the production of high-carbon goods and services. Low-carbon lifestyles approved of and practiced by the public are therefore crucial for the development of low-carbon societies. Without undermining the quality of daily life, there is still significant potential for energy conservation and emissions reduction if communities take appropriate action.

### 3.3 Multiple Issues

From a literature review and a system analysis, nine key issues faced by low-carbon development were identified: greenhouse gas (GHG) control, ecological capacity evaluation, regional economic prediction, energy structure optimization, land resource utilization, industrial structural adjustment, low-carbon industrial chains, low-carbon transportation systems and low-carbon tourism (Xu et al. 2014). By solving these issues, it is possible to ultimately achieve low-carbon development goals such as slowing climate change, promoting sustainable human development and realizing a harmonious development between humans and nature. Specifically, these issues can be divided into three main categories.

Category I: fundamental issues. GHG control, ecological capacity evaluation and regional economic prediction belong to this class. Reasonable GHG control, sufficient ecological carrying capacity, and appropriate economic development targets are the foundations of low-carbon development.

Category II: significant issues. Energy structure optimization, land resource utilization and industrial structure adjustment belong to this class. Energy, land and industry are the carriers of economic development. Low-carbonized energy systems, land use and industrial structural adjustment are significant for low-carbon development.

Category III: crucial issues. Low-carbon industrial chains, transportation and tourism are included in this category. Industrial chains, transportation and tourism are high carbon emissions sources. Developing low-carbon industrial chains, transportation and tourism are crucial for low-carbon development.

In summary, coping with climate change is a complex problem that has an on-going impact on all levels of the society. Neither a global treaty nor a local scheme alone is sufficient. To solve climate issues over the long run, individuals, families, firms, communities, and governments across multiple levels need to act jointly to substantially change behavior.

## 4. Cybernetic Framework

Before solving complex systemic problems, a comprehensive understanding of the system is required. Cybernetics, the science of organized complexity, was initially proposed as a framework for understanding communication and control in complex systems (Clemson, 1984). To establish the cybernetic framework for coping with climate change, we established an integrated framework based on viable solutions that have several interconnected components. Further, since LCD issues are complicated and involve intertwined objectives such as continuing economic growth and improving social progress while maintaining the ecological balance, a model system with various solution models is required.

### 4.1 Viable Solutions

Hardin (1968) noted that the tragedy of the commons had no technical solution as it required a fundamental extension of morality. Without a profound change in the way people live, it is questionable that scientific knowledge and technological innovation alone can control carbon accumulation and lead to a low-carbon society. In general, there are three types of approaches that have generally been applied to curb carbon emissions and promote low-carbon development: technological, economic and social-ecological.

(1) The technological approach focuses on the development of new low-carbon technologies to address the global challenges of energy security, climate change and economic growth. To accelerate the development of low-carbon energy technologies, the International Energy Agency (IEA) was developing a series of low-carbon energy technology roadmaps covering the most important technologies such as carbon capture and storage, energy-efficient buildings and wind energy to advance global development and encourage the uptake of key technologies to achieve international climate goals.

(2) The economic approach moves within a cost-benefit framework, generally assuming the status quo to be the baseline against which the costs and benefits are to be measured. On this basis, carbon-reduction relevant economic measures such as energy and industrial structural optimization have been adopted and popularized. For instance, the EU and China signed the EU-China Statement on Climate Change in June 2015 to intensify bilateral climate cooperation for the development of cost-effective low-carbon economies in the areas of mitigation policies,

carbon markets, low-carbon cities and GHG emissions reduction.

(3) The social-ecological systems perspective refers to the ethical values used when analyzing the threats posed by climate change to the ecosystem and to human populations. The social-ecological costs are broadly defined and not-easily quantifiable using economic analysis. Further, as these costs cannot be eliminated through technological innovation, a system reconfiguration is required. In this regard, Ostrom (2009) established a general framework to analyze sustainability in social-ecological systems, which included LCD systems suffering from climate change.

While technical solutions such innovative green technologies could promote low-carbon development, they must be accepted by the majority, most of whom also need to change their attitudes towards low-carbon lifestyles. Therefore, as Hardin stressed, social norms also need to change. Although clearly not all such changes can be implemented by legally binding rules, changes in such social norms can be induced by passing climate-related economic policies, ecological legislation and through the influence of informal institutions. By integrating the essentials of the technological, economical and social-ecological means, we established a cybernetic framework to cope with climate change.

## 4.2 Integrated Framework

Theoretically, in an *n* countries world, where $e_i$ is the carbon cutback of country *i* and global abatement is $E=\Sigma_i e_i$. Each country's benefits depend on global abatement: $B_i=B_i(E)$, while the costs are dependent on each country's own emissions reductions: $C_i=C_i(e_i)$. The optimal condition is when each country chooses a situation where the marginal cost of abatement equates with the marginal benefits from this abatement. Realistically, however, mainly because of information asymmetry, the prisoner's dilemma prevents the attainment of a mutually beneficial strategy or a cooperative emission scheme, resulting in sub-optimal or non-optimal outcomes. To break through the dilemma and to optimize carbon abatement, prompt sufficient information communication is needed to decrease transaction costs. Therefore, we established an integrated framework for low-carbon cybernetics, consisting of four components with interrelated features: a cloud platform for data analysis, meta-synthetic engineering for decision support, a polycentric approach for extensive consultation and various functional modules for goal achievement, as shown in Figure 2.

Being inherently trans-disciplinary, cybernetics focuses on how systems use information and models and controls actions to attain and maintain their goals, with an understanding that the feedback processes information manipulation and decision making (Heylighen and Joslyn 2003). Figure 2 illustrates the feedback processes for information transfer and decision making across the four components.

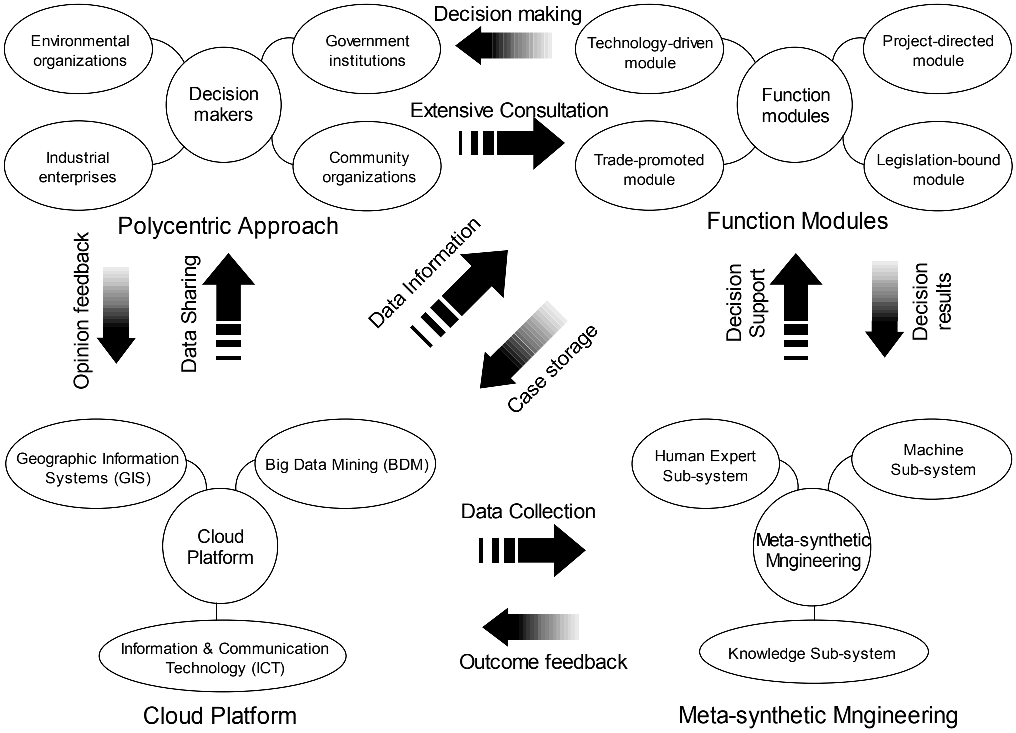


**Figure 2** Integration Framework for LCD cybernetics

**Component 1: A Cloud Platform for Data Analysis**

An understanding of how the climate system functions and behaves is critical to support decision-makers who are seeking to develop climate change strategies. Such an understanding comes from the increasing volume and complexity of climate data. As policymakers need to access climate data to make informed decisions, a new paradigm which allows for unfettered data access is needed (Overpeck 2011). In this regard, a climate data cloud platform could be constructed. Cloud platforms are made up of networked intelligent electronic devices that allow users cloud capacity for climate-related cloud computing. Building a cloud, however, is a complex undertaking, as it requires an integration of the hardware, the installation and configuration of software and a robust solution that allows for large scale access, high performance and reliability. A climate cloud platform should have three key elements; Geographic Information Systems (GIS) information, Information and Communication Technology (ICT) tools and Big Data Mining (BDM) availability.

GIS provides policymakers with a synthesized view of climate change so as to implement adaptation and mitigation measures based on informed decisions on the global to local influences of the climate system. The GIS data collected should be able to be shared by personal computers and mobile devices such as GPS. ICT tools such as teleconferencing and videoconferencing have significantly reduced business travel GHG emissions and also provided an unobstructed information exchange environment for multi-level and multi-agent decision making. The popularization of ICT can significantly increase information exchange and inter-organizational communication to allow for joint decisions on how to deal with climate change. Most importantly, based on multi-model ensemble methods for evaluating and combining simulation output from multiple climate models, BDM can provide innovative, data-driven solutions and has the capability of extracting useful information from large amounts of spatio-temporal climate data.

**Component 2: Meta-Synthetic Engineering for Decision Support**

Tackling climate change is a complex systems engineering problem composed of three processes: psychological processes as to the perception of climate change and the acceptance of a low-carbon transition, physical processes involving mitigating and adaptive actions towards climate change, and social processes involving climate change collaboration, communication and consensus. Based on the cloud platform, workshops on meta-synthetic engineering (HWMSE) could be developed to manage the complicated decision making processes (Gu and Tang 2005). The HWMSE, by combining decision making with advanced information technologies and high-performance computing, can harness the collective knowledge and innovations from diverse experts by synthesizing the data, information, models, knowledge and experiences into an interdisciplinary, complex climate change process.

The HWMSE is an information processing system composed of three sub-systems; a human expert sub-system, a machine sub-system and a knowledge sub-system; and takes advantage of the expert system as the qualitative intelligence and the machine system as the quantitative intelligence to generate in-depth knowledge which is stored in the conceptual knowledge system to solve unknown or new issues. In a climate change setting, the HWMSE can also operate as a web-based group decision support system by utilizing on-line workshops and opinion mining, thereby providing a flexible platform for negotiation and people-machine collaboration, knowledge creation and wisdom emergence for creative solutions to unstructured LCD issues.

**Component 3: A Polycentric Approach to Extensive Consultation**

The ultimate quality of group consultation can be constrained by the participation and communication degree of the multiple stakeholders. Instead of a centralized institutional approach, Ostrom developed a polycentric approach to cope with climate change (Ostrom 2014) which enabled users of the resource to establish a self-management system to reduce information and enforcement costs. Ostrom’s approach is more reliable because at the global level, the response to climate change has been intergovernmental. Further, inside a nation, stakeholders such as government institutions, industrial sectors, environmental organizations and local communities should all be involved in developing climate strategies and policies.

Ostrom's team, using lab experiments, found that communication between members of a group was the key to establishing cooperation and highlighted the importance of developing opportunities for constructive interactions between individuals (Janssen et al. 2010). Following this premise, with an expedited communication channel, stakeholders on multiple levels can improve institutional capabilities through collective action and shared knowledge and experiences on the specific benefits, thereby contributing to a reduction in the asymmetries between countries and regions. As the low-carbon concept is enhanced within government institutions, community organizations and local authorities, building coordinated mechanisms can be more effective when small-to medium-scale governance units are linked through information networks based on the cloud platform.

**Component 4: Functional Modules for Goal Achievement**

The most fundamental contribution of cybernetics is in its explanation of goal-directed behavior; an essential human characteristic for dealing with significant issues such as climate change. Utilizing the meta-synthetic and polycentric approach offered on the cloud platform, cross-sectoral communication by multiple stakeholders can build on existing expertise and knowledge in individual modules such as technological innovation, projects, trade and legislation to develop an integrated view of low-carbon growth opportunities and priorities for multiple issues on multiple scales.

(1) Technological innovation-driven module. Effective carbon emissions reductions and climate change mitigation require a redirection of investment flows from high to low-carbon technologies. Technological innovation can lead to the clean and efficient utilization of coal, an enhancement of the added value of oil gas and coal bed gas, the development of renewable new energy sources and effective and efficient carbon capture and storage. The development of low-carbon technologies could provide the driving force for a low-carbon economy.

(2) Project-directed module. Due to many factors such as economic performance, switching costs, path dependence and lock-in effects, it is difficult to achieve short-term large-scale development for low-carbon economies over a wide region. However, investment into and the implementation of assistance or pilot projects to deal with particular low-carbon issues such as land resource utilization and low-carbon tourism can serve as carriers of low-carbon development without the need for additional inputs.

(3) Trade-promoted module. According to Coase Theorem, the exchange of commodities can be regarded as a trade in property rights; therefore, carbon emissions can also be exchanged. Carbon trading has proven to be an effective solution to unbounded carbon emissions under the current market framework. Therefore, many countries and regions such as the EU and China have been actively engaged in the development of global or national carbon trading markets.

(4) Legislation-bound module. To promote low-carbon development, governments from developed and developing countries have set minimum energy permission targets and have discharged permission standards through

legislation and law enforcement; for example, the US Low Carbon Economy Act of 2007, Japan's Low Carbon City Promotion Act of 2012 and Ireland's Climate Action and Low Carbon Development Act of 2015. In general, this module focuses on authoritative, open and stable practices.

These function modules are closely related to global climate treaties. Specifically, the UNFCCC has insisted that developed countries provide technology transfer and financial assistance to developing countries to tackle climate change. Flexibility mechanisms imbedded in the Kyoto Protocol, IET, CDM and JI provide legislative support for developed and developing countries to trade carbon emissions and conduct emissions reduction projects; for instance, through the CDM mechanism, industrialized countries are able to buy certified emissions reductions from projects that mitigate emissions in developing countries.

## 4.3 Model System

Scientific decision making requires the support of reliable data and suitable models; essential elements in the cybernetic framework. As data can be collected on the cloud platform, climate models need to be carefully chosen and systematically combined in accordance with the many previously mentioned low-carbon issues. However, as these issues involve different scientific disciplines, the solutions are seeking to achieve different goals such as economic growth, social progress improvements and ensuring ecological balance. This diversity, therefore, requires integrated modeling which accounts for all relevant disciplines. After comprehensive consideration, the problem-leading model system shown in Figure 3 was established, which has a data-driven decision process and a series of problem-solving models.

This is a data-driven decision process which has different scenarios for the data input from model operations and four types of data output response plans (i.e. blue, yellow, orange, and red) for policy development possibilities. During this process, the optimization and simulation box allows decision makers to collaboratively conduct in-depth analyses and discussions on LCD-involved key issues using an integrated model. Depending on the complexity of the problems, a systematic pedigree of sub-models can then be established. The key challenge is ensuring transparent linkages to integrate all sub-models into the overall integrated model. For this, a meta-unit of the integrated model which integrates a mathematical model and a behavioral model is needed. The mathematical model allows for planning optimization and policy simulation and the behavioral model reflects the feedback from experts and decision-makers on the operating results. The interactions between these two models allows for the merging of the models.

Given the complexity and changing nature of climate change problems, there are no single, optimal solutions that can simulate all low-carbon processes. Systematic models such as uncertain multi-objective programming models, systems dynamics model, econometric models and ecological carrying capacity models, therefore, need to be developed across multiple scales and decision-making units so as to accurately simulate and solve key low-carbon issues. Generally, there have been three model categories: operation models, solution models, and simulation models. Operation models are primarily multi-objective programming models that have been used to identify and calculate the optimal objectives for low-carbon development. Solution models specifically refer to traditional solution methods and the hybrid intelligent algorithms needed to solve multi-objective programming problems. Simulation models have been the premier tools used by researchers to analyze complex and dynamic systems. The categories and functions of these models are shown in Table 1.

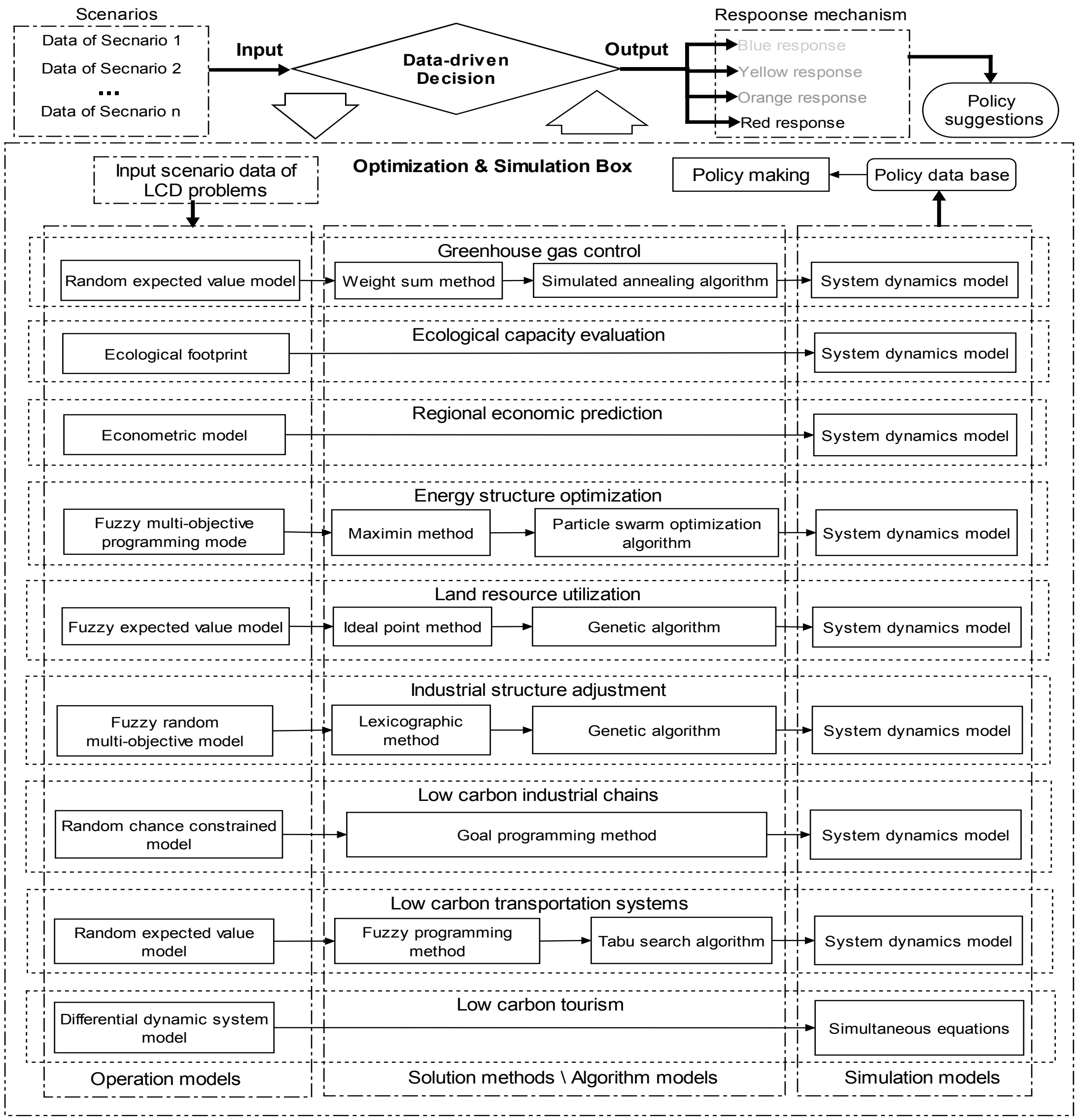


**Figure 3** Problem-leading models system

**Table 1** Categories and functions of the models

| Category | Model | Model function |
|---|---|---|
| I | Ecological footprint | Ecological footprint capacity evaluation with ratio analysis, supply & demand balance analysis and comparative analysis |
| | Econometric model | Specifies the statistical relationship between various economic variables in economic systems for an economic situation analysis |
| | Multi-objective programming model | Simultaneously optimizes two or more conflicting objective functions under a set of constraints, such as emissions reduction, economic growth, and industrial limitation |
| | Differential dynamic system model | Uses applied mathematics to describe the behavior of complex dynamical systems by employing differential or difference equations |
| II | Weight sum method | Evaluates a number of alternatives for a number of decision criteria |
| | Maxi-min method | A strategy to maximize the minimum possible payback |
| | Ideal point method | Constructs an ideal solution using classification criterion for the evaluation objects to find the degree of closeness to the ideal solution |
| | Lexicographic method | Ranks objective functions by their importance to decision makers and then resolves each objective function in order |
| | Goal programming method | Extends linear programming to handle multiple, normally conflicting objective measures |
| | Fuzzy programming method | Uses a fuzzy concept to study fuzziness in the decision making process |
| | Simulated annealing algorithm | A generic probabilistic meta-heuristic which locates the best approximation of the global optimum for a given function in a large search space |
| | Particle swarm optimization algorithm | A computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality |
| | Genetic algorithm | A search heuristic that mimics the process of natural evolution to generate useful solutions for optimization and search problems |
| | Tabu search algorithm | A meta-heuristic local search algorithm that can be used to solve combinatorial optimization problems |
| III | System dynamics model | Simulates the behavior of complex systems over time by dealing with internal feedback loops and time delays |
| | Simultaneous equations | A particular specification of the values of all variables that simultaneously satisfies all equations |

## 5. Policymaking Model

Global climate change is a major international policy issue. The formulation and implementation of climate policies is a common task that requires the participation of all people in the world. Adam Smith popularized the idea of the “invisible hand” in his classical work “The Wealth of Nations”, in which it is explained that an individual who focuses only on their own gain is led by an invisible hand to promote public interest. In the climate context, however, “the tragedy” arises when each person is free to emit carbon emissions which together contribute to climate change. What Hardin (1968) advocated was mutual coercion which is mutually agreed upon by the majority of the people affected. To transition to a low-carbon scenario, policymakers need to gather and compile the opinions of multiple stakeholders so as to achieve efficient and fair policymaking mechanisms across multiple levels.

## 5.1 Multilevel Model

To facilitate economic growth and emissions reduction under the threat of climate change, many countries and regions have enforced low-carbon development policies (Skea and Nishioka 2008, Liu et al. 2013, Thompson et al. 2014). However, according to Ostrom's polycentric approach, simply recommending a single government unit to solve global collective action problems is an inherently weak approach. Further, while the formulated policies seem to be beneficial to all participants, they may be vulnerable to the free-rider problem. A strong push for climate actions needs both an "invisible hand" and a "visible hand". The "invisible hand" is the left hand and refers to market-based mechanisms involving "bottom-up" climate actions, and the "visible hand" is the right hand and refers to the legal-based mechanisms involving "top-down" climate actions. In this regard, based on the cybernetic framework, we propose the multilevel model shown in Figure 4 to effectively develop and promote low-carbon policies.

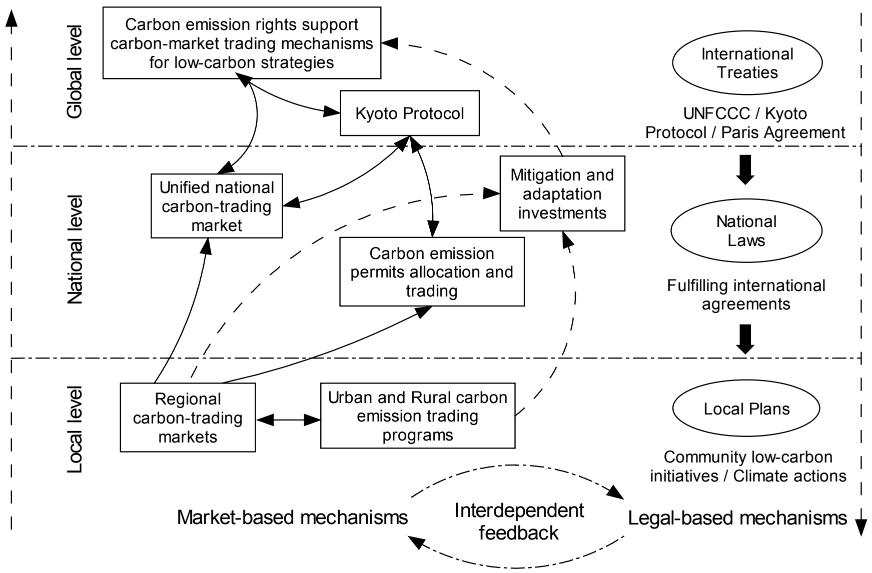


**Figure 4** A multilevel model for low-carbon policymaking mechanisms

Policymakers around the world are facing a challenge to find the most efficient systems to limit global climate change. In recent years, the international community has regarded the right to carbon emissions as a new right for development (Posner and Sunstein 2008). As mentioned above, Ronald Coase advocated assigning property rights to end the tragedy of the commons. The distribution of carbon emissions rights (CERs), which has been widely accepted, is thereby an approach which has dual market and legal properties. According to Arnold (2002), property rights expose a web of interests. To expand the influence of CERs as new property objects, this multilevel model provides a feasible framework for the analysis of the complex relationships in the cross-level carbon abatement rights through the mutuality of market-based and legal-based mechanisms.

The left-hand side of the model indicates the market-based mechanisms. Global, national, urban and rural regions are increasingly using efficient, market-based carbon emissions trading programs as a way to reduce carbon emissions, which is the basis for "bottom-up" climate actions. For instance, the European Emissions Trading Scheme was initiated as a market trading mechanism in 2005, in which large-scale emitters can purchase pollution credits that are then used to invest in carbon reduction projects elsewhere. Based on this market mechanism, more socially acceptable and economically feasible climate policies have been developed as adaptation and mitigation strategies to combat climate change. These policies could better assist the rural poor to adapt to climate change, reduce environmental and economic vulnerability and increase community resilience.

The right-hand side of the model illustrates the legal-based mechanisms. Since the United Nations formulated the Framework Convention on Climate Change through arduous and extensive intergovernmental negotiations, a series of important international documents, such as the Kyoto Protocol, the Bali Road Map, and the Paris Agreement, have successively been released and have been playing a key role in strengthening global consensus on jointly dealing with the climate change challenge and have laid a solid legal basis for CER schemes from "top-down" climate actions. Since international treaties do not usually impact climate plans at the local level, policymakers need to integrate these international treaties into national laws and local plans. CER-related treaties, laws and plans, as catalysts for carbon emissions trading arrangements, can have far reaching influences on global low-carbon development.

The multilevel model combines the top-down system of international climate change agreements with the bottom-up system, through which countries can implement agreements based on national circumstances, capabilities and priorities. This model illustrates the transmission and interactivity of the relationships, activities, and laws from the international to the domestic and local levels, particularly for CERs. Specifically, the cybernetic approach aims to combine market-based mechanisms and legal-based mechanisms through an interdependent feedback process driven by the parties engaged in coping with climate change across the different levels.

### 5.2 Multiple Levels

Within this multilevel model, policies can be divided vertically into global, national and local levels. At the top, agreement on a global level by the governments of the majority of nations is required. This would set the guiding principles for national policy formulation. In the middle, followed by agreements as to the division of each nation's responsibilities, basic policies can be proposed, which provide guidance for local policy formulation. At the bottom, policies are implemented at the local level and subsequently enforced by the public. In addition, participants are more likely to adopt effective rules in macro-regimes; however, as Ostrom (1999) pointed out, if the local authority is not formally recognized by the larger regimes, rules are difficult to enforce. Further, local action could enhance feedback to the national level and exert an impact on the negotiations for international agreements.

#### 5.2.1 Global Level: Negotiation for Consensus

Consensus is the basis of effective policymaking. At the global level, there is now widespread agreement on the need to stabilize the global climate. The debate is on how this stabilization burden should be shared internationally and how it can be mutually enforced. The current approach by world leaders towards climate change is intergovernmental in nature, so no global supranational institution has been developed. Unfortunately the Kyoto Protocol, the best-known ongoing international agreement, has shown itself to be fragile as it has not been widely accepted by national policymakers; therefore achievement of the lofty Kyoto global climate targets and actions has been under a cloud for some time. Fortunately in December 2015, the Paris Agreement was adopted under the UNFCCC by some 195 countries, almost all of the world's nations. The Paris Agreement was the result of arduous international negotiations over two decades and resulted in a legally binding international treaty that established governance mechanisms for an international response to climate change beyond 2020 (Rogelj et al. 2016).

Despite broad agreement on the need for significant long-term global emissions reductions, the challenge remains in the burden sharing across countries. A feasible long-run solution to climate change could be that each country is assigned an equal allocation of emissions quotas per person, with the option of carbon emissions trading. Relatively affluent populations that emit more carbon would need to buy emissions permits from the poorer groups who emit less carbon, with the trade between countries being the same. Further, the allocation of emissions quotas could be dynamically adjusted based on income and living standard variations in each country. The net gains of a stable climate in increasing the global public good should, in most cases, outweigh the differences in costs and benefits at the national level. For positive incentives, financial assistance and technological transfer could guide developing countries in energy efficiency improvements. For credible enforcement, the world community could impose sanctions in the form of trade restrictions on any country that refuses to observe international agreements.

#### 5.2.2 National Level: Cooperation for Policies

The UK government released the Energy White Paper "Our Energy Future - Creating a Low Carbon Economy" in 2003, sounding the horn for low-carbon development. Since 2008, many developed countries, such as the USA, Japan and France have adopted national LCD strategies to recover from the global financial crisis. China, the largest developing country and the largest carbon emitter, has also set itself on a path towards low-carbon economic growth (Liu et al. 2013). However, despite broad agreement on the need for significant long-term global emissions reductions, emissions and climate change impacts are unequally distributed. High emitters that have lower expected impacts have the potential to control concentrations, but have few incentives to do so. On the contrary, countries that have low emissions and higher climate change impacts have greater incentives to control emissions but have little capability. This inequity and mismatch between nations means that joint global action in coping with climate change is difficult.

Different demands lead to different actions. Many countries have made serious international commitments to the development of national policies and schemes to deal with carbon management, especially since there has been increasing pressure on the world's largest and fastest growing developing economies to reduce carbon emissions. For example, the Chinese government announced before the Copenhagen Climate Summit in December 2009 that the carbon dioxide emissions per unit of GDP target for 2020 were 40%−45% lower than 2005 levels. However, because of technical barriers, a developing country which intends to develop a low-carbon economy may not be provided with suitable low-carbon technologies from a developed country. Fighting for one common goal, when countries formulate low-carbon strategies and policies, they must strengthen cooperation rather than fighting individually, as such individualism could lead to a tragedy of the anti-commons (Heller 1998).

#### 5.2.3 Local Level: Knowledge of Localities

The impact of climate change differs depending on the region, geographic location, ecological and economic conditions, prior preparation for extreme weather events and past mitigation and adaptation investment in climate change mitigation. Executable low-carbon strategies depend on the local environment, the developmental stage and current industrial structures; therefore, a policy system that may be effective and efficient in one locality may not be suitable for other localities due to the many local variances and peculiarities. Further, responses that are effective and suitable for one social context could be unsuitable in others. Locally devised solutions, therefore, are more easily enabled by the local community.

Local knowledge is necessary to develop the most effective system for any given locality (Hayek 1945). Local knowledge refers to the unique and traditional knowledge of populations indigenous to a particular geographic area and culture. The significant role of local knowledge in climate change adaptation has been receiving increasing recognition as a strategic resource. In particular, local populations in the developing world largely depend on local knowledge gained through long-term experience when seeking to deal with unprecedented challenges such as climate change. Therefore, local knowledge has to be integrated into climate change adaptation policies. However, climate change has been threatening the roots of traditional knowledge. Therefore, local populations have to renew their local knowledge through learning and training to increase their resilience to the increasingly severe climate change events.

### 5.3 Effective Implementation

Systematic international treaties and national policies alone cannot fix the global climate; effective implementation is also indispensable. In a carbon market under an emissions trading policy, GHG polluters can either buy certificates from the government under a mandatory scheme which gives them rights to emit carbon, or buy carbon credits from someone who sequesters carbon. For instance, the EU emissions trading system, as the world's first major carbon market, has been the cornerstone of the EU policies to combat climate change as well as being a practical tool in cost-effectively reducing industrial GHG emissions. Institutional innovations, therefore, need to be integrated and coordinated to amplify low-carbon policy functions, the operation of which requires comprehensive systems that include all relevant factors and rigorous and powerful measures to ensure implementation. Moreover, the difficulties and challenges encountered during the implementation process could promote innovative revisions to the relevant policies.

Firstly, in terms of government expenditure, low-carbon policies must now play a more important role in the promotion of technical innovation, energy-saving consumption and renewable energy development. A sound government procurement system needs to be established that gives preferential consideration to energy-efficient products and emission reducing innovations. Further, innovative low carbon products should receive low-carbon certification.

Secondly, governments need to establish LCD funds, with carbon taxes being collected as major funding sources. This fund could be used to support energy efficiency improvements, and promote technical green innovations and low-carbon industrial development. Policymakers need to select those policies that can achieve a rational balance between environmental benefit and socioeconomic cost through comparison and scenario analyses.

Thirdly, as climate change is a "global public bad", low-carbon policy development and implementation must prevent potential threats. Where local environmental problems have been resolved, particularly in developed countries, global environmental problems have been exacerbated by developed country policies that have shifted the pollution burden elsewhere, such as transferring production to developing countries. It should be noted that solving domestic climate issues should not result in transnational shifts in environmental pollution.

Dialogue between interested parties, officials, and scientists can promote better mutual understanding to collaboratively solve the "tragedy of the commons" (Dietz et al. 2003). International negotiations to tackle climate change issues must be included on the agenda of important multilateral conferences, not just at UN Climate Change Conferences, but also at OECD meetings, APEC meetings and G20 meetings. As positive interactions can promote public cooperation (Rand and Nowak 2009), exchanging experiences and learning from each other will undoubtedly increase trust and cooperation, resulting in a reduction in transaction costs.

## 6. Conclusions

Carbon abatement is a public good; climate policy thereby is a public-good game. Any independent action to address the climate issue has only marginal effects. As a consequence, simply recommending a single unit or a single solution to solve this global collective action problem is inherently weak. However, this collective action has inherently suffered from free-rider incentives which have tended to exacerbate the uncooperative tendencies of the players. Therefore, policymakers around the world are faced with thorny political issues and complex societal problems when seeking to cope with climate change. While such situations can be extremely difficult to resolve, even on a small scale, this dilemma is infinitely more complex on the global level.

Synergistic effects, nonlinear variation and difficulties in discounting the future have made the climate problem more complex; however, it is not unsolvable. As collective actions and multiple benefits can result from worldwide efforts, this paper, through the application of cybernetic thinking, developed a cybernetic framework and a policymaking model to tackle climate change. Taking low-carbon development as the feasible pathway, a systematic approach that integrated innovative technological and institutional efforts across multiple scales and levels was developed. This type of hybrid solution entails international agreement on a framework goal for carbon emissions reduction, followed by comprehensive policy promulgation and decentralized local implementation.

The earth's atmosphere is common to every nation and every person in the world. Generally, we are against giving the decision-making rights for carbon emissions to each country and each person as such uncommitted private rights could accelerate climate change and lead to a tragedy of the commons. We are also against independent action that lacks co-ordination, as such actions would generate inequality, weaken enthusiasm to reduce global emissions and eventually lead to a tragedy of the anti-commons. Hardin's solution to air pollution reduction involved the curtailing of freedom through control and coercion. While Hardin expressly stated that many may interpret coercion as "arbitrary decisions of distant and irresponsible bureaucrats", this was not necessarily the case. What Hardin, in fact, advocated was "mutual coercion, mutually agreed upon by the majority of the people affected" (Hardin 1968, Hardin 1998).

Fortunately, as a key step beyond the Convention and the Kyoto Protocol, the Paris Agreement, a significant, open-ended, and legally binding treaty, was adopted in December 2015 by a majority of countries in the world, and is expected to have a far-reaching and pervasive influence on the human response to climate change. Recently, the authors witnessed the G20 Finance Ministers and Central Bank Governors Meeting held in Chengdu from July 23 to 24, 2016, at which climate change and the Paris Agreement were important topics. The Communiqué called for the timely implementation of the Paris Agreement and the commitments made by developed countries and international organizations on climate finance. Taking significant climate actions towards a common future and sharing the prosperity of sustainable development requires the dedication and involvement of all people on Earth.

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