The Application of Social-Ecological Systems (SESs) Framework for Environmental Management

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Abstract

This study focuses on the role of formal and informal institutions in managing natural resources, and evaluates their significant impacts on environmental performance of the resource-rich and –poor countries between the years 1990 and 2015. To that end, the overarching Social-Ecological Systems (SESs) framework, which is composed of multiple subsystems at different levels indicating biophysical conditions of the resources, attributes of local community and the rules and norms, is used as the theoretical basis for selecting required variables, collecting data, constructing quantitative models and analysing the results. In this chapter, as the choice of relevant deeper-level variables depends on the particular research questions and the focal level of analysis, the goal is to pick a slice of the SESs that takes account of effective variables, through which the pattern of interactions and outcomes is affected. Especially, the degree to which people are self-organised for maintaining the earth's atmosphere (improving air quality) is of interest. Therefore, this research is devoted to introducing the SESs framework, and criteria we used for separating the relevant attributes of the framework that optimally describes the implications of different types of institutions on reducing environmentally degrading activities. The results of Fixed-Effect and IV panel data models seem to confirm the positive role of formal institutions (democracy score) on reducing environmental degradation (CO_2 emissions).

Introduction

The world is currently experiencing the major threat of global warming, which is mainly derived from the dramatic increase in population, overexploitation of natural resources, and higher levels of pollution. Earth's atmosphere as one of the open-access resources is largely disrupted by the polluted-intensive human activities. The concentration of Green House Gasses (GHGs), as the most pressing common problem that future generations will confront, causes severe problems like climate disruptions, ozone depletion, reduction or extinction of different species (i.e. loss of biodiversity), emerging diseases, and thus collapsing many social-ecological systems operating at different temporal and spatial scales (Kinzig *et al.*, 2013, p. 164; Ostrom, 2009, p. 419; Ostrom, 2008b, p. 10; Ostrom, 2007b, p. 1).

Since the industrial revolution, significant volumes of toxic gasses including Carbon Dioxide (CO_2), Sulphur and Nitrogen Oxides (SO_2 & NO_2), emitted from production and consumption of fossil fuels, power plants and industries, on the one side, and other gasses like Methane (CH_4) made by livestock,

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on the other side, help cause global warming. In addition, the substantial growth in the rate of deforestation and overharvested timbers, while contributing positively to the local people's livelihood especially in developing countries, resulting in an increase in the effects of global warming through releasing more emissions to the atmosphere. In fact, deforestation amplifies the effects of locally-produced GHGs, which can spread over large areas and affect people globally (Ostrom, 2010a, p. 550; Ostrom & Cox, 2010, p. 3).

In other words, while the effects of global warming are universal, its roots are local; hence, it is expected that many actors at different levels including individuals, private and public manufacturers, and local and national governments make the required decisions to recover from global warming (Ostrom, 2010a, p. 550). For instance, within a household, decisions on the means of transportation, purchasing fuel-efficient cars, recycling household waste, and reducing energy consumption by investing more in renewables (e.g. solar panels), will impact the budget and the amount of released GHGs into the atmosphere. Likewise, firms including government offices, which their decisions affect their budgets and emissions' level both in small and large scales, are responsible for consumption of more than 70% of the electricity and 40% of GHGs emissions in the United States (Ostrom, 2016, p. 262: 272-273; Ostrom, 2010a, p. 552-553). Therefore, to solve the dilemma of global warming, daily activities of a wide range of different chunks of the society must change considerably in favour of conserving the environment (Ostrom, 2010a, p. 551-552).

Indeed, global warming is a universal collective-action problem since its extreme adverse effects are the cumulative results of degrading activities done by millions of actors worldwide. In this vein, the accepted collective-action theory assumed that finding long-term solutions for decreasing the environmental degradation such as a reduction in CO_2 emissions and the use of energy, is dependent on the existence of an external power to monitor people and impose sanctions on those who do not take proper actions. Since, it is commonly believed that, people will not change their behaviours voluntarily (Ostrom, 2010a, p. 555). However, the outcomes of empirical studies on Common Pool Resources (CPRs) challenged the conventional idea, and argue that participants will put a great deal of time and efforts to address the collective issues. It states that whenever people are well informed about the future costs of their current degrading activities, higher levels of interpersonal trust and respect will be built among themselves. Thus, environmental-friendly actions will be taken without the presence of any external authority (Ostrom, 2010a, p. 555).

During the past couple of decades, as nations have failed to stop the extreme Carbon emissions and major deforestation, controversial debates over who caused the substantial GHGs emissions initially, and thus should pay its destructive costs have been taking place on a global level (Ostrom, 2016, p. 271; Ostrom, 2010a, p. 550). It has been discussed that a universal enforceable treaty is required for coping with global warming. Therefore, establishing effective governance arrangements for combating the environmental tragedy is considered as the first mandatory action (Ostrom, 2016, p. 267; Ostrom, 2008b, p. 10). The Kyoto Protocol (1997) is one of the significant international treaties on climate change, which is approved and signed by more than 180 countries worldwide[2]. However, even among those countries, there are still some disagreements on the extent of the decline in emissions, the responsibility for previous emissions, and valid instruments on mitigating the adverse effects of pollutions on a global scale (Ostrom, 2016, p. 267; Ostrom, 2010a, p. 555). Even though finding a long-term solution essentially needs to be supported by converged global efforts, a little enforceable international consensus has been reached by all countries yet (Ostrom, 2010a, p. 550).

The fact that the global negotiations have not led to an environmental agreement where all countries committed to can be due to the *(i)* nature of such environmental problems (non-excludable beneficiaries) (Ostrom, 2010a, p. 550). On the one side, each of us at multiple scales has been contributing to this tragedy to various extents. On the other side, reducing emissions by some people, firms or state governments benefit a larger portion of the society. Hence, there are always some members in every community that do not contribute at all or at an appropriate share to avert this tragedy, in which a risk of free-riding activities has always been existed on the costly efforts of others (Ostrom, 2016, p. 259-260, 271; Ostrom, 2010a, p. 550: 555). In addition, *(ii)* the inadequacy of local and regional efforts for reducing air pollution is another reason. While the level of GHGs emissions may be spread over the atmosphere rather equally, its adverse effects unevenly affect people and regions by their geographical, ecological and economic conditions. Therefore, as benefits cannot be limited to those who have invested time and energy in conserving the environment, all countries must implement the established climate abatement policies; even the ones in Africa and Latin America[3] that are classified as low-emitters today (Ostrom, 2016, p. 270).

Although, there is a rather high agreement on the threat of global warming among scientists; the significance and urgency of dealing with the current major air pollutions have been decreasing among people worldwide[4] (Ostrom, 2016, p. 259). It is a major problem, as such collective-action issues involve millions of actors at multiple levels around the world who negatively influence the atmosphere with their polluting activities. Whether they are willing to pay the relevant costs, they would all receive advantages of clean air. Therefore, without exaggeration, it is the largest dilemma of all time, in which institutional solutions at the multiple levels should be proposed (Ostrom, 2016, p. 260, 262; Ostrom, 2010a, p. 551).

In order to delve more into this collective-action issue, after reviewing the need for managing natural resources, we will focus on the Social-Ecological Systems (SESs) framework and its subsystems, introduced and developed by Elinor Ostrom. In the fourth section, to illustrate how the complex framework fit into the current research's attributes, we rely on three criteria of *(i)* particular research question, *(ii)* focal level of analysis, and *(iii)* empirical limitations for supporting the employed combination of variables that are effective enough in the process of achieving the desired outcome.

[2] United States was the only country that has not ratified the protocol.

[3] If they left excluded from the agreement, they will probably increase their level of pollutions in future and worsen the quality of the environment, and may also undermine the efforts of others by behaving as free-riders.

[4] More people, nowadays, believe in the exaggerations of such ecological issues like global warming and climate change.

Further, all the revisions made to the framework, its core subsystems and their internal multi-tiered variables will be presented and discussed in the fifth section. In the next section, the empirical results of estimating the relationship will be discussed. Finally, the last section concludes the discussion.

The Necessity for Governing the Environment

The terms "environment" and "development" have been defined as "where people live," and "how people try to improve their lives," respectively[5]. In order to achieve sustainability, a development must ensure that "it meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, p. 8). During the past century, however, ecosystems have been degraded faster relatively to any other periods in the history[6]. While it has produced substantial benefits in terms of economic development and well-being, the costs and risks of nonlinear collapse in ecosystem services and poverty have been increased. Without a doubt, these significant problems depreciate the expected benefits of future generations from CPRs (MEA, 2005, p. 15).

Sufficiently large open-access resources, in which any person can easily enter and harvest the potential benefits, while decreases the available resource units to others and thus take away the benefits that might be enjoyed by them—like harvesting timbers for consumptive purposes or releasing pollutants into atmosphere— cannot be restricted to those who strive for their conservation. If independent individuals plan to achieve significant outcomes, not only for themselves but also for the ones who did not participate in, they should not, then, seek short-term material benefits. Because, two conditions of *(a)* maximising short-term benefits and *(b)* making independent decisions, unlikely lead to environmental-favourable outcomes. Therefore, a multi-level management system is needed to limit harvesters, without which the resources will be destroyed (Ostrom, 2012b, p. 130; Ostrom, 2010a, p. 551; Ostrom, 2008ab, p. 24; 11).

The conventional theory in environmental conservation calls for an external power to monitor participants' actions, and impose penalties on those who do not voluntarily change their behaviours to reduce their pollutions. Accordingly, three flawless management structures have been recommended for maintaining natural resources (Ostrom, 2012b, p. 130-131; Ostrom, 2008a, p. 25). For example, some authors (Lovejoy, 2006; Terborgh, 2000) suggested the imposition of government ownership, initially proposed by Garrett Hardin (1968), for managing natural resources. They argue that conservation is achievable if only the central government set and support environmental goals through the imposition of law.

However, others including Demsetz (1967) emphasised on the system of private-property right as the only method for avoiding the tragedy of commons and sustaining the environment, since it provides enough economic incentives for owners to make the resources sustainable. They argue that when one does not possess a resource, he/she has no long-term interests in maintaining that resource over time,

[5] The World Commission on Environment and Development (WCED).

[6] Based on the comprehensive report conducted by Millennium Ecosystem Assessment (MEA, 2001-2005).

and thus cannot act favourably toward its sustainability (cause destruction). Finally, it has been observed that some communities were successful in managing their resources (e.g. fisheries, forests, etc.) by establishing robust local institutions. Therefore, "common property management," which is dependent on the capacity of local communities and their users in developing a sustainable resource governance, has been proposed as the third type of ownership (Ostrom, 2012b, p. 133; Ostrom & Cox, 2010, p. 2; Ostrom, 2008a, p. 25).

Large extent of the literature, so far, concentrates on the adoption of any of the aforementioned governance regimes as a single solution (one-size fits all recommendation or cure-all policy) in order to stop the environmental degradation (Ostrom, 2007b, p. 1; Ostrom, 2008a, p. 24). For example, the first two governance regimes (public and private ownership) frequently prescribed as effective systems for governing natural resources, while failed and succeeded examples of implementing each of them have been recorded extensively. Therefore, the same rules that fit well into one setting, may not succeed in another (i.e. there are not any optimum policy that can be prescribed for all natural resources) (Ostrom, 2012b, p. 133: 139; Ostrom & Cox, 2010, p. 2).

Proposing panaceas by some researchers for maintaining complex natural resources is built on two false assumptions. First, they assume that all environmental problems such as air pollution or maintaining biodiversity are comparable, while they are entirely different from one another. Second, all individuals involved in different commons have the same preferences, enough information, and equal power to act; while, several studies found that people' behaviours facing the same situation vary considerably. These are implicitly reflected in Scott Gordon's (1954) static model on a fishery, which has been used for decades for explaining the reasons behind the overharvesting of CPRs (Ostrom, 2012b, p. 139; Ostrom & Cox, 2010, p. 1). In fact, by proposing 'one-size-fits-all' solution as the only remedy, we will be causing more damages to our highly valued resources.

Therefore, there will be no optimal solution for reducing environmental pollution given the complexity, instability and multilevel nature of collective public goods. Rather, instead of relying on stick-figure and simple static theoretical and mathematical models, we need to adopt more complex approaches (A dynamic multi-level system), and learn how to implement right social and ecological policies for coping with severe environmental degradations (Ostrom, 2012b, p. 139; Ostrom, 2008a, p. 28; Ostrom, 2007b, p. 3). It is not uncommon that, sometimes, in a particular setting all forms of governance are appropriate for sustaining that resource (Ostrom, 2007b, p. 4; Ostrom, 2009, p. 419). For instance, several resources are now co-managed by governments and locals working together, or by combining government and private ownership like cap and trade (Ostrom & Cox, 2010, p. 4; Ostrom, 2008b, p. 11). Therefore, resources can be governed through three types of ownership, where depending on the settings, each of which individually or even jointly can be implemented.

As a result, co-management (polycentric governance), which is a complex arrangement of multiple governance regimes (i.e. the interaction of local and central state institutional structures), should be adopted for managing natural resources (Ostrom & Cox, 2010, p. 4). Polycentric governance stresses the major roles of small- and medium-scale units (Ostrom, 2016, p. 261-262), in which several authorities at different scales work together, contributing to the reduction of GHGs emissions (Ostrom, 2010a, p. 551). Within a specific domain (e.g. household, firm, province, local and national governments), each unit has independent power to devise rules and norms, and within each unit, users can have the advantage of using local knowledge and learning from others' trial and error processes (Ostrom, 2016, p. 271-272; Ostrom, 2010a, p. 552). Hence, this system improves the level of learning, adaptation, trust, cooperation among users, and sustainable outcomes (Ostrom, 2010a, p. 552).

Moreover, to address environmental issues, adopting polycentric governance can be useful, since it includes three following factors: *(a)* undertaking an analysis on local level can be affected by larger external factors such as economic and politic decisions, which in this case, an inclusion of larger institutional arrangements can improve the assessment; *(b)* local users are highly likely not interested in the implementation of those governance regimes where their preferences, norms and particular characteristics were not included (e.g. in the top-down governmental interventions), which makes the regime less adaptive and failed; and *(c)* on the one side, local communities have a comparative advantage in collecting the required information for maintaining the resource, which would be difficult and costly to gather for the central government; however, on the other side, they have less comparative advantage in governing large CPRs (Ostrom & Cox, 2010, p. 4).

Besides, putting the responsibility of managing contemporary resources' challenges on only regional or international bodies[7] discourage people and local executives to solve global problems that have local roots. In fact, relying solely on one scale as the only solution is an immature resolution. Therefore, as documented by substantial studies, polycentricity is an effective approach since it is developed by different users at multiple levels. However, it might seem disordered to some scientist and policy makers, which are used to prescribe and apply extreme centralisation, privatisation or decentralisation regimes. Although not all governance system is perfect in terms of removing opportunism in the provision of public goods, polycentricity is a useful approach for solving collective problems like decreasing GHGs emissions, in which multiple users at different scales are needed to make costly efforts cumulatively[8] (Ostrom, 2010a, p. 552).

Hence, contemporary environmental problems likely to be handled well by polycentric governance regimes instead of universal ones (Ostrom & Cox, 2010, p. 4). On the national level, the governments can be pressured by the efforts of the small-scale units to take necessary actions for maintaining the quality of the environment. As a result, multiple private and public units can jointly affect the benefits and costs of the policy implementation process (Ostrom, 2016, p. 261: 270). Overall, the discussion held over the adoption of environmental policies by different global, national, and local units as the

[7] On the international level, an enforceable treaty will be worked once leaders of all countries agreed on a set of requirements such as the responsibility for previous emissions and variety of effective instruments for controlling future emissions (Ostrom, 2016, p. 267; Ostrom, 2010a, p. 555).

[8] In a study undertaken by Dietz *et al.* (2009), 17 actions within a household or a firm have been identified, through which they, cumulatively, affect carbon emissions (Ostrom, 2016, p. 272-273; Ostrom, 2010a, p. 552-553).

only solution for reducing all types of pollutions and sustainably maintaining the environment is not meant to undermine the need for any of the policies. However, the intention here is to balance this strategy as the only resolution for coping with environmental issues, and instead develop a system that appreciates the complexity of such collective-action problem, reduce the risks associated with, and facilitate achieving benefits at multiple scales (Ostrom, 2010a, p. 550: 555).

The Analysis of Social-Ecological Systems (SESs) Framework

The diversity of environmental disturbances including GHGs emissions, ozone depletion, potential loss or extinction of species, diminishing natural resources and the threat of massive climate disruption, which are unprecedented in their complexity and involve interlinked ecological and social systems operating at multiple scales are unlikely to have a single reason. However, scientists' and analysts' diverse responses have been limited to simple panaceas (one-size-fits-all recommendation), through which destructive outcomes have been frequently produced (Ostrom, 2007b, p. 1).

In order to find proper resolutions to prevent resource destruction, institutional theorists need to identify the complexity, non-linearity, cross-temporal and spatial scales, dynamism and multivariable nature of social-ecological systems for devising effective rules. (Ostrom, 2012b, p. 139). The factors that are also mentioned by Holling *et al.* (1998, p. 352) and Simon Levin (1999, p. 2). They describe the complexity of the environmental problems as inseparable natural and social systems problems, which in nature are non-linear across temporal and spatial scales and have unpredictable behaviours. These complex problems have multiple reasons and an evolutionary character (historical dependency), which feed back to the systems throughout the time. Besides, the increasing size of the population and level of economic development intensify this complexity (Ostrom & Cox, 2010, p. 1). Combining these factors with "humans," who are capable of controlling the system on the one hand, and making problems on the other, have made the governance of CPRs challenging (Basurto *et al.*, 2013, p. 1; Ostrom, 2012b, p. 139; Ostrom, 2008a, p. 28; Ostrom 2007a, p. 1).

Given this complexity and instability of such problems, in order to design effective institutions for sustaining the interlinked systems, the structure of any resources and how they might change over time must be analysed first (Ostrom, 2012b, p. 141). For instance, we must first recognise the complexity of climate disruptions' causes and effects, become well-informed about it and also capable of distinguishing effective policies from the pool of strategies. While some of these strategies lead to a reduction in GHGs emissions, others have no real effect, or might even worsen the current situation by providing economic opportunities for some elites to capture the funds through enhancing their rent-seeking behaviours (Ostrom, 2016, p. 271).

Therefore, to understand different institutional structures and theories within an environmental context, a diagnostic framework, which is capable of addressing different environmental problems in diverse settings over time and across scales should be developed (Ostrom, 2012a, p. 22). In this way, the first challenge is identifying combinations of multi-level variables that mainly influence harvesters' motivations within different governance regimes. Hence, various biophysical attributes of resource systems and their generated units must be taken into account, since they jointly affect the users' behaviours that are monitored by a set of different rules imposed by local, national, or even international governing bodies (Ostrom, 2007a, p. 1). In addition, the framework must use a common language (or a set of variables) that enables scientists from different disciplines to match problems embedded in diverse social-ecological contexts with different governance arrangements (Ostrom, 2007a, p. 1).

The Framework

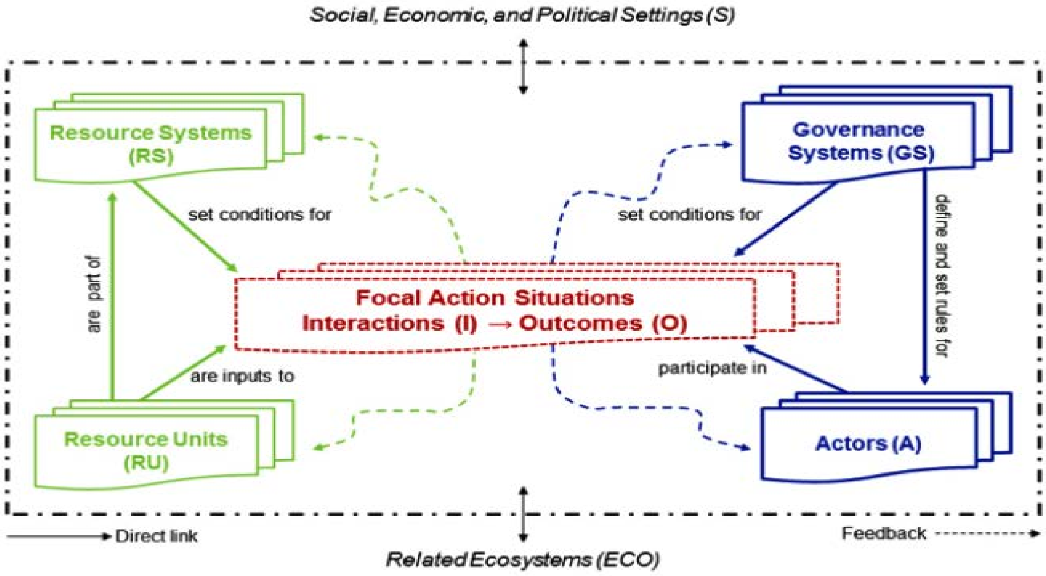
Elinor Ostrom for the first time, in 2007, introduced Social-Ecological Systems (SESs) framework, in which all common pool resources used by individuals are embedded in (Ostrom, 2009, p. 419). SESs is a complex multi-level nested framework that consists of four first-tier components: *(1)* Resource Systems (RS), *(2)* Resource Units (RU), *(3)* Actors (A), and *(4)* Governance Systems (GS). Each of these cores is comprised of a set of attributes that can be individually decomposed into a set of sub-attributes to shape the lower levels of the framework (Ostrom & Cox, 2010, p. 7). In other words, each of the first-tiered variables contains several second-tiered variables, and likewise, each of the second-tiered ones might be further comprised of the third-tier ones, so on and so forth.

Therefore, these attributes, which are arranged into a tiered organisation, make the SESs a multi-tiered conceptual framework. These core categories and their multiple internal variables interact and produce different ecological and social outcomes at time t, through which the main variables and their components will be subsequently affected at time t+1 (Ostrom, 2009, p. 419). They are also linked to and embedded in macro-level social, economic, and political settings and related ecosystems. These key components can also be further unpacked into multiple deeper-level variables (McGinnis & Ostrom, 2014, p. 4; Nagendra & Ostrom, 2014, p. 4; Basurto *et al.*, 2013, p. 2).

The SES diagram (adopted from McGinnis & Ostrom, 2014) present a very simple conceptual map and an overview of how characteristics of *(i)* resource systems and *(ii)* their produced units, *(iii)* the users of those resource units, and *(iv)* the governance system interact with one another and produce outcomes at a particular temporal and spatial scale. All of these characteristics are affected by larger social, economic, political and ecological contexts (Basurto *et al.*, 2013, p. 2; Ostrom, 2007a, p. 2).

Further, in each social-ecological system, users take the units of a well-defined resource system out, and hence, lead to the destruction of that resource system under the absence of adequate governance arrangements. However, the opposite occurs as well. Users are capable of sustaining the resource system if an overarching governance system, which fits the broad settings and other ecosystems, was determined by the dual-role actors. Accordingly, the processes of destruction and conservation are two significant forms of Interactions (I) and Outcomes (O) that are positioned in the heart of the SES framework called "Focal Action Situation" (McGinnis & Ostrom, 2014, p. 3-4).

Figure 1. The Social-Ecological Systems (SESs) framework (McGinnis & Ostrom, 2014)



As depicted in Figure 1, the revised SESs diagram, which is slightly different from the initial design of SESs, illustrates how the core components work together in a unique social and ecological context. Fundamentally, the SES framework enables researchers to analyse the underlying reasons for success and failure in managing natural resources. In this process, a special set of actors who withdraw resource units from a particular resource system under a given set of rules and governance regime, are likely to produce a certain structure of interactions and outcomes (Ostrom, 2012a, p. 24; Ostrom, 2007a, p. 2). By studying the SES framework, therefore we are able to find rules that cause preservative or destructive outcomes such as overharvesting, sustaining, conflicts, or stability for an individual resource system in a particular socioeconomic and political context. Although the initial framework has been developing progressively in the years 2009 (Ostrom), 2010 (Ostrom & Cox), and 2014 (McGinnis and Ostrom), it is currently a powerful tool for carrying out compelling analysis on complex natural resources in different contexts globally (McGinnis & Ostrom, 2014, p. 1). Therefore, developing such framework for investigating the impacts of different types of institutions on individuals' incentives, behaviours, and actions is essential in managing natural resources (Ostrom & Cox, 2010, p. 1):

The Subsystems

SESs framework includes eight primary sub-systems, which can be divided into two groups of four. The first group includes four core components of Resource Systems (RS), Resource Units (RU), Governance Systems (GS), and Actors (A). As can be seen from the diagram, each of them is placed in solid green and blue boxes followed by multiple boxes showing that there might be some simultaneous actions taking place within each of them. Although, these subsystems are relatively separable, they are connected in some way to each other. For instance, RUs are parts of the RSs and inputs to the whole system, as they are being extracted by users continuously. Likewise, the users (As) who participate in the situation through extracting RUs from the RSs, are affected by the rules set by GSs, through which their actions and behaviours are being controlled. In other words, two cores of the RSs and GSs set conditions for As who use the generated RUs. Therefore, the notes attached to the arrows in the diagram, highlight their connections.

The second group, however, can be further arranged into two sections. First, the Interactions (I) of four first-tier components and their generated outcomes (O), which are positioned in the "Focal Action Situations." In fact, all actions taken by multiple actors at different scales are placed in the action situations as inputs, which will be later transformed into outcomes. Depending on the extent and type of the interactions, the focal action situation may involve one to four top-tier components (McGinnis & Ostrom, 2014, p. 4; Ostrom, 2011, p. 23; Cox & Ostrom, 2010).

Second, the broad Social, Economic and Political Settings (S) and Related Ecosystems (ECO), which are linked to the cores. The various outcomes drawn from the action situations, not only impact the entire SES and each top category at time t+1, but also are affected by the exogenous settings and related ecosystems, simultaneously. These dynamic connections, in the SES figure, are shown by green and blue dashed lines originated from action situation, and black dotted-and-dashed line that surrounds the interior parts of the SES.

As previously discussed, all the core categories are comprised of multiple second-tier variables, which are illustrated in Table 1. The following list is acquired from McGinnis and Ostrom (2014):

Table 1. List of the SESs framework's second-tier variables

Top-tier Categories and Their Internal Second-tier Variables					
1	***Social, Economic, and Political Settings (S)***				
S1	*Economic development*	*S2*	*Demographic trends*	*S3*	*Political stability*
S4	*Other governance systems*	*S5*	*Markets*	*S6*	*Media organisation*
		S7	*Technology*		
2	***Resource Systems (RS)***	***3***	***Resource Units (RU)***		
RS1	*Sector (e.g., water, forests, pasture, fish)*	*RU1*	*Resource unit mobility*		
RS2	*Clarity of system boundaries*	*RU2*	*Growth or replacement rate*		
RS3	*Size of resource system*	*RU3*	*Interaction among resource units*		
RS4	*Human-constructed facilities*	*RU4*	*Economic value*		
RS5	*Productivity of system*	*RU5*	*Number of units*		
RS6	*Equilibrium properties*	*RU6*	*Distinctive characteristics*		
RS7	*Predictability of system dynamics*	*RU7*	*Spatial and temporal distribution*		
RS8	*Storage characteristics*				
RS9	*Location*				
4	***Governance Systems (GS)****	***5***	***Actors (A)***		
GS1	*Policy area*	*A1*	*Number of relevant actors**		
GS2	*Geographic scale of governance system*	*A2*	*Socioeconomic attributes*		
GS3	*Population*	*A3*	*History or past experiences*		
GS4	*Regime type*	*A4*	*Location*		
GS5	*Rule-making organisation*	*A5*	*Leadership/ Entrepreneurship**		
GS6	*Rules-in-use*	*A6*	*Norms (trust-reciprocity)/ Social capital**		
GS7	*Property-rights system*	*A7*	*Knowledge of SES/ Mental models**		

GS8	*Repertoire of norms and strategies*	*A8*	*Importance of resource (dependence)**
GS9	*Network structure*	*A9*	*Technologies available*
GS10	*Historical continuity*		
6	***Interactions (I)***	***7***	***Outcomes (O)***
I1	*Harvesting*		
I2	*Information sharing*	*O1*	*Social performance measures (e.g., efficiency, equity, accountability, sustainability)*
I3	*Deliberation processes*		
I4	*Conflicts*		
I5	*Investment activities*		
I6	*Lobbying activities*	*O2*	*Ecological performance measures (e.g., overharvested, resilience, diversity, sustainability)*
I7	*Self-organising activities*		
I8	*Networking activities*		
I9	*Monitoring activities*	*O3*	*Externalities to other SESs*
I10	*Evaluative activities*		
8	***Related Ecosystems (ECO)***		
ECO1	*Climate patterns*		
ECO2	*Pollution patterns*		
ECO3	*Flows into and out of focal SES*		

Note: The table includes the most recent revisions made to the original lists of the second-tier variables (2007; 2009). The adjustments include relabelling, relocation, and addition or elimination of variables within each core category. Especially, Governance Systems (GSs), here, refers to the tentative list of variables.*

Since the introduction of SES in 2007 to its latest revision in 2014, the main cores were remained unchanged; however, the internal variables within each core have been developing in various ways; some variables were added or eliminated, some labels were changed, or even a set of relevant variables were entirely revised and, improved. For example, an alternative list of second-tier variables introduced for governance systems and replaced the original one by McGinnis & Ostrom (2014, p. 7). Accordingly, over time, the list of second-tier variables was further unpacked, refined and upgraded to help researchers with identifying important factors that affect the shape of interactions and outcomes within a particular SES framework. The aim of all these changes was in the interests of generalisability of the SESs framework by extending the framework for an application to any complex social-ecological systems.

These critical variables are required to be learnt, identified, and measured by researchers in studying diverse resources. In order to have a meaningful understanding of top categories and their internal variables, one needs to delve deeper into each second-tier variables, find lower-tiered ones, and explore the relationships amongst them (Ostrom, 2007a, p. 1-3). While the framework considers a broad set of potentially applicable variables, all of them are not relevant to every study as SESs are partially decomposable[9] systems. Thus, one must choose appropriate lower-tiered variables based on three factors of *(i)* the particular questions under study; *(ii)* the type of the SES; and *(iii)* the spatial and

[9] Decomposability has three aspects:

1. SESs is a multi-tiered framework, denoting the conceptual division of variables into categories and subcategories.
2. Categories and subcategories are relatively separable, which means that they are independent from each other but eventually affect each other's performance.
3. Different combinations of variables lead to a different interactions and outcomes.

temporal scales of analysis (Nagendra & Ostrom, 2014, p. 4). Therefore, diverse sets of focal action situations can be studied by identifying and picking the potentially relevant variables (Ostrom, 2007a, p. 2). In addition, listed variables are not ordered based on their importance, as it varies in different studies (Ostrom, 2009, p. 420; Ostrom, 2007a, p. 2). Since SESs are nested, multi-tiered and hierarchical, they are inherently complex; therefore, a theory is required to guide the analytical focus (McGinnis & Ostrom, 2014, p. 1). Hence, by using the framework, researchers are enabled to build and test a variety of theories and models, based on the selected relevant variables, which are required for collecting data, conducting fieldworks, and analysing the studied SES's outcomes in terms of sustainability (Basurto *et al.*, 2013, p. 2; Ostrom, 2012a, p.23; Ostrom, 2009, p. 420).

To apply the SES framework in any case, a two-step process should be followed: (1) we must have a clear research question. In some cases, the question under study might involve the broad social, economic, and political settings (S) as a focal system, in which one compares these settings across a number of countries throughout the time. While in some other cases, one may examine a particular RS located in an area within a specific setting (S) in a single time, thus, needs to explore in the second- or third-tier variables to explain the difference in the outcomes achieved (Ostrom, 2007a, p. 7). In other words, depending on the question under study, both micro and macro variables individually or jointly have significant impacts on the outcomes. Therefore, selecting the focal level of analysis should be considered as the entry point for studying any SESs (McGinnis & Ostrom, 2014, p. 10).

For undertaking the analysis, (2) we need to pick the relevant lower-tiered variables. The process of identifying influential variables involves attributes of resources' conditions and socio-cultural aspects of communities that can have significant impacts on human behaviours and social-ecological outcomes. However, as SESs are decomposable, we only need to consider third- or fourth-tier ones, when their associated second-tier variables are found to be important and influential in the pattern of interactions and outcomes. Selecting important variables that are required to be measured for achieving desired results is considered as the second step of the process (McGinnis & Ostrom, 2014, p. 10). Therefore, researchers' goals in studying SESs must be recognising a particular combination of variables, which likely generate long-term sustainability of natural resources at a specific spatial and temporal scales. In fact, it is unlikely that anyone can record the variations in all of the listed variables. Therefore, one should hold some of them fixed and focused on the ones that make significant impacts on the structure of interactions and outcomes (Basurto *et al.*, 2013, p. 9; Ostrom, 2007a, p. 3; Ostrom, 2007b, p. 11).

Fitting the Framework into This Study: A Slice of the SES

The current study is attempting to address one main question and three sub-questions. The key research question is what the effects of formal and informal institutions are on the environmental conservation[10]. Considering this, we are particularly looking at the role of the political system (democracy and autocracy) and level of trust (social capital) across countries in order to achieve

[10] Environment, along with economic and social equity are known as three pillars the sustainable development.

conservation. Therefore, this cross-country empirical research tries to estimate the impacts of formal and informal institutions on the environmental performance of resource-rich and –poor countries—in terms of fossil fuels, e.g. oil, gas, minerals—by employing different statistical techniques including IV and GMM panel data regressions, between the years 1990 and 2015. To that aim, The SES framework is taken as a conceptual basis for collecting data, selecting required variables, constructing quantitative models and analysing the results.

Large extent of the existing empirical literature mostly concentrates on the relationship between formal institutions and economic growth and development, while there is a lack of a sound institutional foundation in empirical studies regarding environmental development (Rommel, 2015, p. 1), especially in resource-rich countries, where major governance deficits are frequently observed. In other words, the implications of institutions on environmental performance have not been addressed clearly in previous research. In addition, there is an ambiguity in the relationship between institutions and environmental protection. Thus, a further investigation is needed for clarifying the correlation. Therefore, this study attempts to *(a)* empirically examine the significant impacts of institutions on environmental conservation, to check which type of institutions (formal versus informal) promote developmental performance more. This will particularly enable us to delve deeper into informal institutions as one of the important motivations of this research.

However, what makes this study unique is that *(b)* we try to quantify the relationship by using the complex SESs framework that has been mostly adopted for conducting qualitative case studies (at the micro level). In essence, we are trying to push the frontier forward by employing such a framework on a macro level (across countries) and testing it empirically. For undertaking this study, as previously discussed, we are required to pick a slice of the framework that matches the best possible the research's characteristics. In this process, I will include main criteria of *(i)* the focal level of analysis, *(ii)* major attributes of core categories, *(iii)* studied sample of countries, *(iv)* employed empirical methods, and *(v)* availability of reliable data[11] into my analysis to identify and limit the number of effective variables in order for narrowing down the focus of this research and meeting the empirical specification's requirements.

Broad Social-Economic-Political Settings (S): Focal Level of Analysis

Since it is a cross-country study, focusing on two groups of resource-rich and –poor countries, the focal level of analysis is at the country level (macro scale). In fact, the research questions mainly involve broad settings and macro-level variables that are capable of capturing variations across countries and time. Therefore, it is important that the broad Social, Economic, and Political Settings (S) are incorporated into the regression models, as they represent the macro level of analysis. The category of Settings (S) includes seven second-tier variables, which give us an overall picture of a country's capacity in combating environmental degradation. They capture variations in different areas of

[11] Data availability is one of the major concern of this study especially on the variables representing formal and informal institutions.

economic, demographic, political, and technological across nations. Initially, all of the seven variables are planned to be included in the regressions as control variables[12].

In addition, there might be a Kuznets type (non-linear) relationship between economic development (S1) and pollution levels, meaning that as income grows the pollution first worsen but later improves[13] (Levinson, 2008, p. 1). Therefore, to capture the income-pollution pattern, a squared form of the indicator (e.g. GDP per capita) should be added as another control to the equation. Thus, the Settings' variables along with the squared form of the economic development (S1 squared), which are consistent with the theory and also fits the focal level of analysis, will be included accordingly. The broad settings can be accounted as the most influential aspect of this research as it determines how far is required to go down or up in the hierarchical SES framework to find appropriate variables that have significant effects on the ecological performance of countries. Likewise, the process of selecting relevant variables, while is not finalised yet, potentially limited to the second-tier variables of all the top-tier categories. The deeper-level variables (e.g. third-tier, fourth-tier, etc.) might be used for further clarifications on choosing the right top variables that are essential to be included in the model.

Resource Systems (RSs) and Resource Units (RUs): Earth's Atmosphere

Resource Systems (RSs) denotes a top-tier category, in which their produced units are consumed by a set of actors who interact with one another under the conditions set by the overarching governance system. RS category consists of nine second-tier variables on the biophysical characteristics of a resource system such as type (e.g. forests, water, and atmosphere) and size of the resource, its location, clarity of the resource boundaries, productivity level, and available storage, etc. For instance, the storage characteristics of a resource system like forests explain the amount of carbon that can be stored in it, which may vary across different resource systems and units (Ostrom, 2007a, p. 3).

Resource Units (RUs), while is a separate sub-system, has a compositional relationship with RS showing how closely connected they are (McGinnis & Ostrom, 2014, p. 6). Hence, both will better be explained together. RU is another core subsystem, which consists of seven internal variables ranging from its mobility and growth rate to its value and spatial and temporal distribution. As illustrated in the SES diagram, on the one hand, RUs are part of the RSs as they are withdrawn by harvesters; however, on the other hand, they are inputs to the particular action situations, since they are consumed

[12] Subject to the availability of reliable data.

[13] The inverse U-shaped plot, which shows the pattern of income and pollution is first described by Simon Kuznets (1955) and later popularised by Grossman and Krueger (1995). It has been labelled as "Environmental Kuznets Curve." The EKC summarises the relationship and interaction of three parts of *scale*, *composition*, and *technique*: *(i)* If a country is developing, in the initial stage, the *scale* of activities increases, thus pollution will increase with the economic growth; *(ii)* If the *composition* of the produced goods is changing, because of changes in tastes or trade pattern, then the pollution may either decrease or increase with growth; and *(iii)* if countries use less pollution-intensive *techniques*, growth lead to less pollution. Consequently, the world's poorest and richest countries are expected to have relatively better environments, compared to the middle-income ones that are the most polluted.

by different actors at different scales. The whole process is also managed and monitored by the governance systems.

In the IAD framework, unique attributes of the RS and its RUs are considered as "exogenous factors," since they are not directly in the hands of officials; but are treated as a driver of changing circumstances. These ecological attributes make significant contributions in choosing right operational rules and organisational structures (Ostrom, 2012a, p. 23-24). In other words, the governing rules for a specific system might be entirely different from the rules used for another. For instance, in fisheries where the resource units (fishes) are mobile, the rules will be different from the ones used for fixed units (trees) of forests.

In this study, the earth's atmosphere, which is largely disrupted by the concentration of GHGs, is selected as a RS. Among all types of environmental problems that the world is currently experiencing, major threat of global warming is the most pressing common problem. It is mainly derived from the dramatic increase in population, overexploitation of natural resources and a substantial level of polluting activities. Particularly, extensive emissions of harmful gasses such as Carbon Dioxide (CO_2), Sulphur and Nitrogen Oxides (SO_2 & NO_2), and Methane (CH_4) cause a severe concentration of GHGs. Substantial deforestation also strengthens the adverse effects of global warming through lowering the world's capacity in storing Carbons and thus releasing more to the atmosphere, resulting in climate disruptions, ozone depletion, loss of different species, and emerging diseases. Therefore, abatement of air-related issues, as the most complex social dilemma that future generations will confront is opted for studying in this paper.

In this vein, employing an indicator that can adequately capture the air-pollution levels across countries (like CO2 emissions) is the first step for indicating how polluted the RS is. However, since the atmospheric concentration of various GHGs stems from different resources, we need to look at different types of natural resources to check where the pollutions come from. This is important because certain types of resources lead to certain types of pollution. For example, CO_2, SO_2 and NO_2 are emitted from using fossil fuels and power plants, while CH_4 is made by livestock. One way to account for this might be to place an indicator in the regression model representing what type of resources the country possesses (oil, gas, minerals, or livestock). In addition, even CO_2 can be sourced from different sectors, such as transport system, energy section, and different types of fuels. Hence, along with CO_2 emissions, other environmental indicators, such as Methane's or other GHGs' can be used as dependent variables. This will enable us to address where the pollution comes from (production or consumption), thus, the results of this study would help analysts and policymakers to adopt right policies that target the specific problem.

One other important attribute of the chosen RS is the atmosphere's productivity level, which is derived from the production-consumption rate. In other words, the Oxygen (RU) generated from the RS, is consumed and contaminated in various ways (and different rates) by all people around the world, indicate that it varies considerably across countries and thus, should be included in the equation.

However, there is no such data available for measuring productivity level directly. As a result, we can instead draw on factors through which the natural rate of RS's productivity is mainly affected. Factors such as the ratios of forests and use of fossil fuels that help to store and release Carbons in the atmosphere can be substituted with the productivity level. Therefore, by entering these factors into our model we might be able to capture changes in the consumption-production rate roughly. It is worth mentioning that, by including "forest" into the analysis along with earth's atmosphere, we are studying two RSs concurrently. In this situation where more than one resource system is involved, based on the purpose of the study, they can be treated as a whole one aggregated component (an integrated resource system), if they are inter-related (McGinnis & Ostrom, 2014, p. 6-7). Here, as both resource systems are closely inter-linked[14], they are treated as one aggregated category.

Finally, the chosen RS and RU also fit the focal level of study, as they involve all countries worldwide. Since, *(a)* it is an open-access RS, in which everyone has equal access to it as no effective limitations for any actors can be established; and *(b)* RUs are mobile and, thus, the locally-produced pollutions can spread over regions unevenly and affects people globally. We are trying to take all the required variables; however, considering the studied RS and its RUs and the focal level of analysis, we are obliged to pick ones, through which comparing countries across the different timespans become applicable. Therefore, the employed variables indicate particular biophysical attributes of the earth's atmosphere and its generated Oxygen. They are unique in-nature and different from the attributes of other types of natural resources such as fisheries, pastures, etc.

Governance Systems (GSs) and Actors (As): Formal and Informal Institutions

Previously, it has been discussed that there is no panacea for solving problems related to governing CPRs, and hence, the idealised governance arrangements including public, private and local community ownerships either individually or jointly can work in different cases. In other words, if one or two management systems can achieve positive outcomes in one particular case, it does not mean that it leads to the same positive results in another case(s). Basically, each regime consists of *(i)* a set of rules specifying rights to access to the resources, *(ii)* monitoring the actions, and *(iii)* imposing sanctions on those who do not comply with the rules to maintain natural resources (Ostrom & Cox, 2010, p. 5). The institutional diversity must fit the local communities' socio-cultural norms, while at the same time, compatible with the RS's and its RUs' biophysical conditions (Ostrom, 2012a, p. 22).

The Institutional Analysis and Development (IAD) framework[15] takes all these aspects into account and thus enable scholars and policymakers to consider *(i)* the rules in use (not only the formal written ones); *(ii)* characteristics of the resource system including key biological, chemical, and physical conditions, and the type of the good (ranging from private to public goods); and *(iii)* the level of trust and shared norms as the qualities of a society (McGinnis & Ostrom, 2014, p. 2-3). The term

[14] Forest improves the air quality and helps to prevent global warming through storing Carbon and releasing Oxygen into the atmosphere.

[15] IAD framework, which was taken initially by Kiser and Ostrom in 1982, is a conceptual map that links the institutional arrangements to the social-ecological outcomes (McGinnis & Ostrom, 2014, p. 2).

"institutions" in IAD refers to the rules and shared norms, designed and developed by both government authorities and people, and used by individuals who regularly interact in a wide range of rule-structured situations at multiple scales (Ostrom, 2012b, p. 130; Ostrom, 2008a, p. 24). This is also consistent with North's definition of institutions (1990, p. 3). He describes three important features of institutions as: they are *(i)* rules of the game that constraint people's behaviours; *(ii)* are humanly devised; and *(iii)* their effects are through the incentives (Acemoglu & Robinson, 2008, p. 2).

In his opinion, institutions can be divided into two categories of *(i)* written rules and laws determined by an external authority that give information to individuals about what actions are permitted or prohibited (formal institutions); and *(ii)* unwritten norms such as customs, traditions or cultures (the identity of a specific community) that define codes of behaviour, which are required to be followed by each individual person (informal institutions) (Ostrom & Cox, 2010, p. 5; North, 1990). These rules can be modified as people learn more about the consequences of their own activities, resulting in either better or worse outcomes for themselves and the surrounded environment (Ostrom, 2008a, p. 24). Overall, institutions are useful for mediating self-interest, enhancing collective actions, and reducing uncertainties (Ostrom & Cox, 2010, p. 5).

These biophysical, social, and institutional elements, known as contextual factors in IAD, are inputs to the decisions made by individuals. Aggregated decisions and actions generate patterns of interactions and outcomes, which will take place in the "action situation" centre, denoting that both IAD and SES frameworks are closely inter-connected. In fact, the SES is built on the foundation of IAD, enabling researchers to analyse the interactions of different components of social-ecological systems that affect outcomes within an institutional context[16] (McGinnis & Ostrom, 2014, p. 2-3; Ostrom & Cox, 2010, p. 1). In the SES context, these institutional attributes are embedded in two social cores of Governance Systems (GSs) and Actors (As) (Rommel, 2015, p. 97).

GS, as one of the most important cores, set conditions and define rules for actors who participate in depleting and/or consuming resource units in an action situation, where they generate the structure of interactions and outcomes. The rules and policies made by local and national authorities affect multiple actors' incentives and behaviours who are involved in the process. It initially contained eight second-tier variables; however, McGinnis and Ostrom (2014), revised the whole structure of internal variables subsequently. They introduced a tentative list of 10 potential second-tier variables, in which all original variables were included, albeit in different locations and organisations. For example, original GS1 and GS2 are now combined and added as third-tier variables to GS5 in the new list.

Further, three types of rules, which were initially grouped as GS5-7, are now combined and rearranged as one broad variable (GS6: rules-in-use). In addition, they added other factors to GS as second-tier

[16] When action situations are strongly affected by influential resource systems' and units' particular attributes, the SES framework is likely to be used more; while the lack of the said variables might emphasise on the use of IAD framework[16] instead (Ostrom, 2011, p. 23; Cox & Ostrom, 2010). It shows the degree to which the SES and IAD frameworks are closely inter-related.

variables. One of them, for instance, is policy area (new GS1), which its role is exactly like the resource sector in a particular RS. Regime type (new GS4) is another proposed variable referring to a political system that can be interpreted in two ways of democratic and autocratic, or monocentric and polycentric (McGinnis and Ostrom, 2014, p. 8-9).

Another category that contains factors on institutional attributes is Actors (As), which was initially known as Users (Us). It can be considered as the most important top category in the SES framework since users' behaviours and actions result in both destruction and conservation in a social-ecological system. On the one side, they expropriate the units generated by a resource system in the absence of adequate governance arrangements and hence lead to the destruction of that resource system. However, on the other side, they are capable of sustaining the resource system, if the implemented governance system fit well into the social, economic and political settings and related ecosystems. Thus, it can be said that actors are dual-role users. This top-tier category consists of nine second-tier variables ranging from the number of relevant actors and their socioeconomic characteristics to the level of trust and social capital in their communities, all of which potentially affect the patterns of actors' interactions with one another and resources within the action situation (Ostrom, 2012a, p. 23-24).

As discussed in the previous part, global warming is a complex collective-action problem and a social dilemma as its global extreme adverse effects are the cumulative results of local degrading activities made by millions of actors worldwide. Therefore, in order to stop environmental degradation, it is essential that many actors at multiple levels make the required decisions. In other words, solving such a challenging problem involves different parts of the society, ranging from households to the state governments, to take required actions focusing on decreasing both total energy use and emissions of particulates. Therefore, the presence of both formal and informal institutions in mitigating the air pollutions is of utmost importance.

However, previous research found a mixed relationship between formal institutions (e.g. regime type) and environmental conservation (Kinda, 2011; Acheson, 2006). On the positive side, democracy as a good formal institution supplies more environmental public goods and policies.[17] Because in a country with democratic institutions *(i)* people can collect information easier and, thus, are more aware of environmental problems (freedom of media). Also, *(ii)* they can express their preferences (freedom of expression), and *(iii)* create lobbying groups to put pressures on the government (freedom of association). Hence, the resource-users take account of the social costs of their environmentally degrading activities. Moreover, *(iv)* people have the right to vote. Thus, political leaders are prompted to implement environmental policies to satisfy them.

[17] An increase in civil and political freedoms (democratic system) decreases certain types of air pollutants (CO_2, SO_2 and NO_2), land degradation, deforestation and pollution in water quality (Bernauer & Koubi, 2009).

On the other side, in some studies (Midlarsky, 1998)[18], democracy is considered as a factor of economic prosperity, which hurts the quality of the environment. It has also been emphasised that in democracy, *(i)* the short duration of electoral cycles motivates political leaders to adopt favourable policies to their re-elections; and *(ii)* elected governments may have shorter planning horizons, while many forms of environmental degradation develop slowly over a long period of time (e.g. global warming). Thus, the social costs of current economic behaviour and political choices often appear over the long term and burden future generations. Besides, *(iii)* population is another important issue, as there is an almost perfect correlation (99.8%) between global population growth and GHGs emissions (Newell & Marcus, 1987). Therefore, while autocratic countries can restrain people, democratic systems must respect their freedom. Accordingly, democratic governments undersupply environmental goods relative to non-democratic regimes.

Therefore, based on the theory, it is important to take account of the regime type when the role of formal political institutions in achieving environmental conservation is being studied. Therefore, in order to clarify the link, a factor representing the ruling system (such as democracy score, political constraints, etc.) is required for capturing variations within the political system across countries. Although, the overall quality of formal institutions is, to some extent, taken by the regime type, the inclusion of a variable that can also assess the quality of different types of rules (operational, collective, and constitutional)[19] might be required. It will enable us to have a more accurate measure of the quality of formal institutions in each country (e.g. rule of law, rules-in-use, etc.). Therefore, subject to the availability of reliable data, the inclusion of both variables are important for obtaining an in-depth estimation of formal institutions.

Further, some authors including (Acemoglu, Johnson, and Robinson, 2001; 2003) has taken protection against expropriation risk as a proxy variable for measuring the quality of property-right system[20] across countries. While, it is a good measure of the quality of economic institutions across countries, and might be used in future as an alternative institutional variable for testing the robustness of our regression results; it is not relevant in this research. Since, the studied RS (atmosphere or air quality) is an open-access resource (public good), in which everyone has access to it (i.e. no one can be

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[18] He found a negative relationship between democracy and CO_2 emissions, soil erosion, and deforestation.

[19] Based on the IAD framework, rules can be classified into three main categories of operational-, collective-, and constitutional-choice rules, which made for shaping the formal structure of actors' daily interactions. They can be defined and distinguished as *(i)* either individual or collective choices, among available options, that are practical (i.e. rules, norms, and strategies that should be/are not available to actors fulfilling specific roles defined by the group); *(ii)* rules related to constraining individuals' (citizens and officials) operational activities, while they, themselves, are subject to changes and adjustments by constitutional-choice rules; and *(iii)* rules related to who should be permitted and more powerful to participate in making operational rules (McGinnis & Ostrom, 2014, p. 3; Ostrom, 2011, p. 19). In this way, any of the policy instruments used by multiple organisations (e.g. governmental, policy agents, etc.) can also be rotted and grouped in three forms of operational, collective and constitutional levels (McGinnis & Ostrom, 2014, p. 9).

[20] The IAD framework can also explain this: *(i)* what can be counted as one's legitimate property (constitutional level)?; *(ii)* what types of property can be expropriated for public use (collective level)?; and *(iii)* how can we distinguish actors with the right to harvest, manage, exclude and alienate from all participants (operational level)?

effectively limited from extraction). Therefore, theoretically, its inclusion should not make any changes to our results.

In addition, different countries run by different ruling systems implement various policies targeting areas of environment, health, trade, economic, etc. Among them, those that strongly adopt a number of national environmental policies and/or sign international treaties for preventing degradation must be differentiated from the others, therefore, are required to be recorded. Consequently, an indicator on a number of the above-mentioned policies should be included in our model. The degree to which that the adopted policy encourage changes in people's behaviour depends on the willing cooperation and social norms in the short- and long-term. If it is highly efficient and fairly enforced, then the costs of enforcement become lower. When people believe in a policy, they comply without being forced by the government. Therefore, trust in government is critical for solving the collective-action problem (Ostrom, 2010a, p. 551-552).

Furthermore, a political system with deep historical origins is likely to be more stable than the governance arrangements that are made recently. They are also expected to produce different outcomes from the new ones. According to the common theory, new governments tend to implement economic-related policies, which are unfavourable for the environment, to satisfy public interests. While, long-lasting governance systems have longer horizons which enable them to make more environmental-friendly decisions. Therefore, in societies which are more politically stable (or durable), regardless of their regime type (whether they are democratic or autocratic), governments supply more environmental public goods. As a result, researchers are encouraged to include a variable for capturing the historical continuity (McGinnis & Ostrom, 2014, p. 10). In this study, it has been captured by the S3 (political stability).

On the other side, as this major ecological issue involves millions of actors worldwide, to solve the dilemma in the long-term, the conventional manner of doing daily activities of large portion of the population must change considerably in a way that bring about environmental conservation, though cost them more time and energy, eg., changing in the pattern of personal transportation or recycling household waste, etc. However, in the case of this particular RS, whether they are willing to pay the relevant costs, the fact that they would all receive advantages of clean air, make people less motivated to contribute at all or at an appropriate share to avert this tragedy. In other words, the risks of free-riding activities arisen from non-excludable beneficiaries embedded in such open-access resources, result in nations' failures to stop the extreme carbon emissions. While, in societies with higher levels of social capital and interpersonal trust—as a proxy for good informal institution—people respect, cooperate and reciprocate more to decrease their unfavourable activities without the presence of external authority. In fact, it is easier to implement policies that require broad-scale cooperation among large portions of the populations. Therefore, a variable on the level of interpersonal trust or social capital will be incorporated into the quantitative model for indicating the quality of informal institutions across countries.

Another important factor that is expected to have a positive association with preventing environmental degradation is educational level. If a large portion of the population is educated, then it is expected that more people are informed about the social costs of their degrading activities and less likely to take such actions. It is strongly supported by extensive research, within which the lack of communication and learning about each actors' behaviours are mainly emphasised as the source of overuse and destruction of open-access resources (Ostrom, 2011, p. 14-15). However, individuals who adopt the norms of communities may change their strategies and then the structure of the situation over time, as they learn more about the results of their past actions. Therefore, a proxy variable for capturing variations in educational level across countries is essential.

Finally, based on what has been discussed, it can be claimed that formal and informal institutions are the main parts of two social cores of GS and A, through which the sustainability of natural resources are dependent on (Rommel, 2015, p. 97). Therefore, it would also be useful to consider the interaction of formal and informal institutions into the model to check the effects of formal ones on environmental performance in different informal institutional quality context (weak or strong). In other words, when there is a higher quality of formal institutions, higher levels of trust (informal institutions) can be beneficial in reducing emissions. In contrast, when the government is not efficient enough, then high levels of interpersonal trust can make the pollutions worse. For example, when people are not happy with governments' policies, the cooperative societies put pressures by refusing to comply with the rules and protesting. Consequently, trust does not necessarily play a positive role in societies, therefore delving deeper into this part to establish a clear relationship is an interesting part of this research.

Focal Action Situations: Interactions (I) and Outcomes (O)

In the "Focal Action Situation," one can identify and analyse multiple actors and their assignments at different levels, which are singularly or jointly interacting in various ways such as cooperating for solving problems, fighting over access, etc. Actions situations, at time t, take all inputs from all of the top-tier categories[21]. The produced outcome(s), then, will subsequently affect the whole system at time t+1. The entire process occurs in the context of the broad social-economic-political settings and related ecosystems. While it is not immediately apparent to observers, it links the outcomes to the relevant variables through the feedback paths (dashed lines) (McGinnis & Ostrom, 2014, p. 6). Therefore, the core subsystems can be considered as inputs and outputs from at least one action situation (McGinnis & Ostrom, 2014, p. 4; Ostrom, 2007a, p. 2).

Among all interactions, self-organising activities are mentioned as the most important one. The term "self-organisation" refer to resource users who invest a great deal of time and energy in conserving the environment to prevent the tragedy of commons. The conventional theory assumes that users never self-organise, since individuals focus on maximising their short-term benefits and not cooperating with each other. This results in overuse of resources unless an external authority such as governments

[21] Depending on the question under study specific combination of several variables (not all) from RS, RU, GS, and A will be taken, and generate several interactions and outcomes

change users' incentives by imposing rules (i.e. solutions) and relevant sanctions (Ostrom, 2009, p. 420). Early studies predicted that diverse harvesters fail to develop required rules and norms for governing the natural resources and thus bring about destructions, if they do not engage in proper communication (Ostrom, 2009, p. 419).

However, analysing individuals who follow the rules and norms (e.g. being trustworthy and reciprocal) through which their costs and benefits are affected, show that if users believe that there are some people (e.g. neighbours) whom they can trust and also available to respond to cooperation with cooperation, then they tend to continue these cooperative activities. Reciprocation provides a chance to achieve substantial long-term benefits through gaining the reputation for being trustworthy and reciprocal (they act as an asset for increasing individual- and joint-level outcomes). Consequently, unlike the self-interested theory of human behaviour; trust, reputation and reciprocity are the main factors that influence individuals' behaviours in social dilemma cases (Ostrom, 2010b, p. 69: 71).

On the other hand, several empirical research has found the opposite, where the resource destruction was accelerated because of the governmental policies. While some users designed and implemented costly governance systems to maintain their resources (Ostrom, 2009, p. 420). In addition, resource sustainability is not caused by the implementation of different types of government, private, and local community ownerships; however, it depends on the users who have trust and confidence in each other (Ostrom, 2010b, p. 71). Consequently, for analysing the relationship between multiple actors and natural resources, an updated theory of collective action is required to consider the levels of trust and reciprocity of those who involved in social dilemmas (Ostrom, 2010a, p. 551).

Since harvesters with a long-term interest in sustainability are more willing to do self-organised activities for governing the resources, a set of 10 second-tiered variables were identified by Ostrom (2009 p. 420-421) as the ones that affect the likelihood of users' self-organisation and engagement in solving collective-action problems. Depending on the context of the study, while all of these 10 second-tier variables might not be relevant to every study and thus not to be used entirely, obtaining their measurements is the first step in analysing the probability of self-organisation among diverse users in a community (Ostrom, 2009, p. 421). Considering the studied resource system, and its unique attributes, the probability of maintaining the earth's atmosphere (self-organisation activities) is relatively lower than other resource systems.

Table 2. Self-Organisation's internal variables

Cores	The Importance of the Selected Variables for Addressing Self-Organisation
Resource Systems	***Size of resource system (RS3)*** *Among three group of small-, medium-, and large-sized territories, the moderate-sized resource systems are likely to be relatively more self-organised, since defining clear boundaries (with signs or fence), monitoring process, and obtaining ecological knowledge are more feasible than the other territorial sizes. For instance, harvesters in very large-sized RSs like forests, or fishers who travel in the ocean are unlikely to self-organise because of the given costs of boundaries, monitoring, and knowledge. Similarly, small territories are also less likely to be maintained, because they do not generate substantial flows of valuable products.*

	Productivity of system (RS5) *The motivation for actors to self-organise is scarcity. Users do not see a need for governing an abundant resource or almost exhausted resource for future. Therefore, the productivity of a resource system has a curvilinear effect on self-organisation across all sectors.* ***Predictability of system dynamics (RS7)*** *If resource users could estimate what would happen if they were to create special harvesting rules or no entry territories, then it means that the resource system is sufficiently predictable, and thus likely to be self-organised. For example, forests are more likely to be self-organised than water systems.*
Resource Units	***Resource unit mobility (RU1)*** *Mobile resource units such as wildlife or water in the river are relatively less likely to be self-organised than stationary units such as trees or water in the lake, due to the costs of observing and managing a system.*
Governance Systems	***Rules-in-use (GS6): Collective-choice rules (GS6-b)*** *Having autonomy or independence in constructing and enforcing some of the rules at the collective-choice level will decrease transaction costs.*
Actors	***Number of relevant actors (A1)*** *The overall effect of group size of actors on self-organisation depends on the other SES variables and the types of management tasks. Because, on the one side, the bigger the group size, the higher the transaction costs of self-organising would be. Due to the higher costs of getting users together and reaching an agreement on required changes, it negatively affects self-organisation. However, on the other side, for doing some costly tasks of managing a resource such as monitoring extensive community, a larger group of people would be helpful because they are more able to mobilise necessary labour and other resources.* ***Leadership/ Entrepreneurship (A5)*** *Self-organisation is more likely when some resource users have entrepreneurial skills and are also respected as local leaders. For example, the presence of college graduates and influential elders is positively linked to better governance.* ***Norms (trust-reciprocity)/ Social capital (A6)*** *The presence of higher levels of interpersonal trust, norms, reciprocity, and sharing moral and ethical standards result in lower transaction and monitoring costs. Social capital is defined based on three attributes of trustworthiness, the existence of networks, and the existence of rules and norms that enhance the ability of individuals to solve collective-action challenges (Nagendra & Ostrom, 2014, p. 4-7).* ***Knowledge of SES/ Mental models (A7)*** *When users have more ecological knowledge of relevant SES attributes and share it with others, the costs of organising will be lowered. For example, users who understand the carrying capacity of the resource (RS regeneration pace compare to the population growth), may not fail to self-organise, and prevent destructions.* ***Importance of resource (dependence) (A8)*** *It has been observed in successful cases of self-organisation, in which actors make great efforts in sustaining the RS, actors are either highly dependent on the RS for their livelihoods, or the RS is highly-valued and so important to them. Otherwise, considering the costs of organising and maintaining a self-governing system, may not be worth the effort.*

Based on the table, the long-term sustainability of SESs is dependent on users and governments to establish rules consistent with the attributes of the resource system and local communities. A process that is known as self-organisation in the SES framework. In other words, self-organisation depends on three main factors of *(a)* formal institutions (such as rules-in-use); *(b)* informal institutions (such as norms, trust or social capital); and *(c)* some characteristics of the resources (such productivity and the importance of the resource). The purpose of this study, hence, is to find a combination of SES variables that are associated with people's ability to self-organise for achieving the desired outcome, which is avoid polluting the atmosphere.

Depending on the amount of the rules and regulations, the resulted outcomes would be different. When there is no limit on the number of relevant actors and their harvesting activities, the increasing benefits from appropriation result in resource destructions and high social costs. In other words, the patterns of interactions and generated destructive or preservative social-ecological outcomes depend on the degree to which the actors *(i)* are self-organised and *(ii)* effectively limited by law. This can be observed by looking at the history or past experiences in using a resource, which can be shown by including the previous years' emissions as a control variable. It shows the difference in previous years' environmental outcomes within each country, which are correlated with and effective on the current outcomes. Regarding the regression model, the lagged form of the left-hand-side variable should be moved to the right-hand-side of the equation to be able to see the impacts of the previous years' pollutions on the current ones. It results from the interactions of actors' behaviours and resources' biophysical conditions, which in turn depends on several institutional, technological and economic factors.

The Studied Sample of Countries: Resource-rich and -poor ones

The natural resources of different countries has become a subject of controversy. During the past two decades, experimental results illustrate that most countries with significant natural resources have not fared well in terms of economic development (a phenomenon referred to as the natural resource curse), whereas a considerable number of countries that have achieved sustainable growth and development possess few resources (Barbier, 2005; Gylfason, 2001; Auty, 1993). The resource-dependent economies of Africa, Latin America and the Middle East, on the one hand, and Japan, Singapore and South East Asia on the other are cases in point. The problem escalates in severity, when some countries like Norway, USA, Australia, and Canada, which are comparable in terms of natural resources, have shown extremely different records of economic progress over the past decades. Furthermore, the 70 resource-rich countries,[22] are more vulnerable to environmental degradation since *(i)* their economic activities depend heavily on depleting natural resources; and *(ii)* due to their lower level of technology, they have to exploit more to achieve higher economic growth and development. Hence, resource destructions are more observed in these countries.

Previous research has identified the lack of proper institutions as the leading cause of their backwardness (Acemoglu *et al.* 2001; 2003; 2014; van der Ploeg, 2011). While growth and development must be both inclusive and environmentally sound to reduce poverty and build prosperity for current and future generations, resource-abundant countries often have failed in this regard, because of their major institutional and governance failures (Stoddart *et al.*, 2011). It is also indicated by World Governance Index (WGI), through which these countries often ranked lower in terms of institutional

[22] IMF categorised a country as a resource-rich one if at least 20% of its total exports' revenues are resulted from fossil fuels.

quality compared to their resource-poor ones with the same level of GDP per capita. Therefore, without having effective institutions to limit users (harvester), resources will be over-harvested (Young, 2003), especially in such countries where not many environmental-friendly policies have been adopted to reduce the pollutions (Ostrom, 2016, p. 271; Ostrom, 2010a, p. 550: 555).

Since possessing natural resources or lack thereof, potentially make significant changes in the air conditions of the countries; the employed sample of the study is divided into two groups of countries *(i)* rich in natural resources including oil, gas and minerals, and *(ii)* poor in such resources. In order to avoid sample selection bias, instead of using the IMF criteria as a basis for splitting the countries into two categories, we use a new index of "total dollar value of resources per capita." It will add up countries like USA, Canada, Australia, etc. that are rich in resources but were not included in the IMF sample as they successfully diversified their economies. This will also enable us to conduct a comparative study on the differences between the countries, on how the relationship between institutions and environmental degradation statistically differs across two sets of countries.

Methodology and Preliminary Results: The Empirical Specifications

The SES framework is taken as the basis for building the regression models and analysing the results. To that end, a cross-country empirical approach is adopted, in which Fixed-Effect and Instrumental Variables (IV) panel data regression models are estimated for evaluating the significant impacts of institutions on environmental conservation. These methods could be beneficial as they can account for endogeneity problems and country-specific unobserved factors that are time-invariant and only uses variation within each country to relate institutions and environmental performance so that reliable estimators can be acquired.

Here, we have taken Log CO2 Emissions per capita (lnco2em) as an indicater for capturing environmental performance. Also, in order to measure the self-organisation, three different variables are used: *(a)* democracy score *(DEMO)* as proxy for formal institutions; *(b)* religious tension[23] *(RTS)* as Informal Institutions; and *(c)* total natural resource rents *(NRR)* as resources characteristics. Furthermore, I use five different variables, which are mentioned in the broad Settings as control variables to show the overall condition of an economy: *(1)* Log GDP per capita *(lngdpr)* for measuring economic development; *(2)* population growth *(POPg)* for showing demographic trend; *(3)* Government Stability *(GVS)*; Freedom of Media *(FOM)*; and (5) total factor productivity growth *(TFPg)* for capturing changes in political stability, media organisation and technological development in such countries, respectively. The table blow shows the expected sign for each mentioned variable:

ENVIRONMENTAL OUTCOME	SELF-ORGANISATION	$\hat{\beta}$	SOCIAL, ECONOMIC & POLITICAL SETTINGS	$\hat{\beta}$
Environmental Performance *(Log CO2 Emission per capita)*	Formal Institutions *(Democracy Score)*	–	Economic Development *(Log GDP per capita)*	+

[23] More ethnic and religious tensions leads to lower level of trust within society.

Informal Institutions *(Religious Tension)*	+	Demographic Trends *(Population Growth)*	+
The Importance of Resources *(Total Natural Resource Rents)*	+	Political Stability *(Government Stability)*	–
		Media Organisations *(Freedom of Media)*	–
		Technology *(Total Factor Productivity Growth)*	–

The opted variables are aligned with the SES framework and effective enough to affect the patterns of interactions and outcomes. In addition, having maximum observations and coverage in terms of a number of countries and years is another reason in choosing the relevant variables. We tried to have the most possible observations in order for obtaining accurate estimations. They are acquired from reliable sources including World Bank Development Indicator (WDI), Polity IV Project, International Country Risk Guide (ICRG), Quality of Government (QoG), and Varieties of Democracy (V-Dem). The employed sample here is 55 resource-rich countries, and the period of study is between 1990 and 2015. Table 1 and 2 show the results of simple OLS, Fixed-effect and panel IV regressions[24] with and without the interaction term of formal and informal institutions.

Table 1

Variable	OLS	FE	IV
Institutionalized Democracy	0.036	-0.014	-0.012
	4.22	-1.97	-2.36
Religious Tensions	-0.018	0.019	0.043
	-1.65	0.92	0.87
Tota Natural Resources Rents	0.006	0.005	0.005
	3.46	2.44	2.23
Log GDP per capita	1.378	0.691	0.791
	67.54	3.66	8.73
Population Growth	-0.087	0.018	0.004
	-5.87	0.97	0.52
Government Stability	0.053	-0.012	-0.014
	3.80	-1.61	-2.61
Freedom of Media	0.221	-0.057	-0.055
	4.99	-1.77	-2.78
Total Factor Productivity Growth	0.001	-0.005	-0.003
	0.20	-1.90	-1.43
r2	0.913	0.498	0.504
N	899	899	826

legend: b/t

[24] Note: All models are estimated with robust standard errors. The first numbers denote regression coefficients and the second ones are t-statistics.

The OLS result says that countries with higher pollution are also the ones with higher quality of informal and formal institutions. But this may just be a correlation. However, the results of Fixed-Effect and IV panel data models on the set of resource-dependent economies, seem to confirm the positive role of formal institutions (democracy score) on reducing environmental degradation (CO_2 emissions). This is consistent with the existing literature, which emphasises the importance of the governments' environmental policies to combat degradation. However, we could not find any significant relationship between ethno-religious tensions and degradation, though, from a theoretical perspective, a positive relationship was expected; since more tensions lead to lower levels of trust in the society, especially in those countries where religious and cultural beliefs play major roles in this process. In the IV regression, refugee population is used as an instrument for religious tension, which is time-variant.Furthermore, an increase in total resource rents will increase the CO_2 emissions, especially in resources like oil and gas, where politicians' rent-seeking behaviour bring about more exploitation and, thus, degradation. In contrast, political stability and freedom of media help to reduce that specific type of pollution. One very compelling reason for these findings is that in societies which are more politically stable (durable), regardless whether they are democratic or autocratic, and more aware of environmental problems, governments supply more environmental public goods and people take the social cost of their environmental-degrading activities into account.

Table 2

Variable	OLSint	FEint	IVint
Institutionalized Democracy	0.084	-0.005	-0.173
	5.55	-0.34	-1.13
Religious Tensions	-0.057	0.013	0.066
	-3.61	0.49	1.36
Tota Natural Resources Rents	0.006	0.006	0.001
	3.49	2.42	0.28
Log GDP per capita	1.389	0.699	0.631
	68.29	3.66	3.26
Population Growth	-0.087	0.018	0.004
	-5.97	0.97	0.39
Government Stability	0.049	-0.012	-0.011
	3.53	-1.62	-1.42
Freedom of Media	0.211	-0.058	-0.047
	4.72	-1.79	-1.68
Total Factor Productivity Growth	0.000	-0.005	-0.001
	0.03	-1.91	-0.42
Interaction of Democ & Relig Tens	0.011	0.002	-0.040
	3.40	0.65	-1.04
r2	0.913	0.499	0.176
N	899	899	826

legend: b/t

In Table 2, we tried to include interaction of formal and informal institutions into the model to check the effects of formal ones on environmental performance in different informal institutional quality context (weak or strong). In other words, when there is a higher quality of formal institutions, informal institutions (trust between people) can be beneficial in reducing environmental emissions. In contrast, when the government is not efficient the trust between people can make the pollution worse. For example, when people are not quite happy with their governments' policies, the cooperative societies put pressures by refusing to comply with the rules and protesting. Therefore, trust does not necessarily play a positive role in societies, and as it shown above the FE and IV results are not significant. Therefore, delving deeper into this part in order to establish a clear relationship can be an interesting field to work further.

In order to see whether the results are consistent across different measures of formal institutions, alternative metrics representing different types of political institutions is used in the table below (Table. 3). Variables like constraints on executives and constitutional rules from PolCon database are added to the model to check for the robustness of results. As it is illustrated below, the results are all consistent in different models showing that higher quality of formal political institutions are negatively correlated with environmental performance. Furthermore, ethnic tensions is replaced with religious one to get the robust estimations for informal institutions as well. It can be seen that the outcomes are remain unchanged across different models.

Table 3. Robustness Test (Formal Institutions)

Variable	IV	IV1	IV2
Religious Tensions	0.043	0.038	-0.029
	0.87	0.81	-0.91
Institutionalized Democracy	-0.012		
	-2.36		
Constraints on Executives		-0.018	
		-2.19	
Political Constraints Index V			-0.075
			-1.89
Tota Natural Resources Rents	0.005	0.004	0.003
	2.23	2.16	1.87
Log GDP per capita	0.791	0.784	0.846
	8.73	8.77	9.52
Population Growth	0.004	0.004	0.011
	0.52	0.49	1.29
Government Stability	-0.014	-0.013	-0.016
	-2.61	-2.53	-2.82
Freedom of Media	-0.055	-0.050	-0.043
	-2.78	-2.50	-2.40
Total Factor Productivity Growth	-0.003	-0.003	0.000
	-1.43	-1.46	0.17
r2	0.504	0.504	0.487
N	826	826	871

legend: b/t

Table 4. Robustness Test (Informal Intitutions)

Variable	IV3	IV4	IV5
Ethnic Tensions	0.083	0.078	-0.069
	0.87	0.80	-0.89
Institutionalized Democracy	-0.010		
	-2.19		
Constraints on Executives		-0.016	
		-2.09	
Political Constraints Index V			-0.107
			-1.96
Tota Natural Resources Rents	0.005	0.005	0.003
	2.05	1.96	1.56
Log GDP per capita	0.799	0.793	0.832
	8.44	8.46	8.51
Population Growth	-0.002	-0.001	0.016
	-0.17	-0.13	1.52
Government Stability	-0.005	-0.005	-0.022
	-0.44	-0.46	-2.39
Freedom of Media	-0.054	-0.052	-0.046
	-2.69	-2.67	-2.34
Total Factor Productivity Growth	-0.003	-0.003	0.000
	-1.49	-1.50	0.07
r2	0.480	0.483	0.483
N	826	826	871

legend: b/t

The initial findings seems to confirm that countries with higher quality of formal institutions are performing better in terms of reducing air pollution towards environmental sustainability. But, the informal institutions were not signifcant in all of our models. Also, the results are consistent across the estimated regressions with different specifications. Although, the present study considers institutions as endogenous across countries worldwide, since they are greatly affected by countries' socio-cultural, historical and geographical preconditions, including culture, religion (e.g. Christian or Muslim), ethnicity, colonial or legal origins, the slave trade, and rugged terrain; finding a suitable time-variant instrument for panel data models has always been challenging for researchers. Hence, further investigations will be still required for exploring a better instrument in order to overcome the endogeneity problem in specifying the model.

Discussion

So far, we showed how the SESs framework can be applied to this empirical study concerning the major roles of institutions in improving environmental quality across all countries and 25 years. In this way, we used the revised version of the SES framework as the theoretical foundation, and updated the list of the variables (through including or excluding deeper-level variables) based on the particular attributes of this research like the questions under study, the focal level of analysis, the empirical specifications, so on and so forth. Since, among all listed interactions and outcomes, the self-organisation activities (I7) and ecological performance measures (O2) are of interest, the specific combination of the chosen variables should be highly-associated with and effective enough in the process of self-organised activities[25] and producing the desired environmental outcome.

To that purpose, a total of 14 second-tier variables,[26] are selected to be incorporated into the regression models. Specifically, eight variables are chosen from three categories of Resource Systems (RS5: productivity of the system- RS5-a: forest & RS5-b: fossil fuels), Governance Systems (GS1: policy area- GS1.1: environment; GS4: regime type; GS6: rules-in-use; GS8: repertoire of norms or strategies), and Actors (A3: history or past experiences; A7: knowledge of SES/ mental models). These variables are linked to and accompanied by five of the broad Settings' variables for capturing variations in economic development (S1), demographic trends (S2), political stability (S3), media organisation (S6), and technology (S7) across countries. Finally, as discussed before, a squared form of economic development (S1-b) will also be included in the model.

In addition, the inclusion of 14 variables in our model can potentially cover nine more second-tier variables as they are either fully or partly linked to them. To avoid any confusion, all 23 variables are presented in a separate table below (Tab. 3), in which the coloured ones are directly included in our model, while the black ones are showing the extras. As can be seen from the table, six factors (out of 10) that are correlated with self-organisation are among the selected variables. While, only three of them (RS5, GS6, and A7) will be included in the analysis directly, the other three variables (RS7, A1, andA7) implicitly and through their association with previously selected variables will be considered. Since the scale of the study is at the macro level; analysis will be limited to the inclusion of second-tier variables only. Still, relevant deeper level variables will also be used in a case that delving deeper into the root causes of a problem within the system is needed. Moreover, the reasons for any inclusion or exclusion of the SES's variables are discussed further in the appendix (Tab. A.1-7).

Table 3. Selected effective SES variables in the process of self-organisation's in achieving ecological conservation

Top-tier Categories and Their Selected Internal Second-tier Variables					
1	***Social, Economic, and Political Settings (S)***				
S1-a	*Economic development*	*S2*	*Demographic trends*	*S3*	*Political Stability*
S1-b	*Squared form of S1*	*S6*	*Media organisation*	*S7*	*Technology*
2	***Resource Systems (RS)***				
RS4	*Human-constructed facilities*	*RS5**	*Productivity of system*	*RS7**	*Predictability of system dynamics*
		RS5-a	*The ratio of forests*		
		RS5-b	*The ratio of fossil fuels*		
4	***Governance Systems (GS)***				
GS1.1	*Policy area (environment)*	*GS3*	*Population*	*GS4*	*Regime type*
*GS6**	*Rules-in-use*	*GS7*	*Property-rights system*	*GS8*	*Repertoire of norms and strategies*

[25] People's ability to self-organise is known as the most important interaction of the SES framework.

[26] The total number of second-tier variables from the broad Settings (7) and three core categories of RS (9), GS (10), and A (9) is 35. Two other subsystems of related Ecosystems and RU are excluded because they are not relevant to this study, due to the empirical limitation and the specific resource system under study. From all the interactions and outcomes in this study, we only focus on two variables of I7 and O2.

		GS10	Historical continuity		
5			Actors (A)		
A1*	Number of relevant actors	A2	Socioeconomic attributes	A3	History or past experiences
A6*	Norms (trust-reciprocity)/ Social capital	A7*	Knowledge of SES/ Mental models	A9	Technologies available
6			Interactions (I) & Outcomes (O)		
I7	Self-organising activities		O2	Ecological performance measures (e.g., overharvested, resilience, diversity, sustainability)	

Note: Self-organisation's internal variables are marked with an asterisk in the table.

In this study, earth's atmosphere is adopted as the Resource System (RS), and the Oxygen generated is the Resource Unit (RU), which is consumed and contaminated in various ways by all people around the world. Due to the specific biophysical attributes of the RS, its RUs and the focal level of analysis, only a variable that is related more to the heterogeneity of the RS's productivity level is found to be effective in the process of interaction and outcome. In addition, human-constructed facilities (RS4)[27] and predictability of system dynamics (RS7)[28], though are important factors, their variations can be captured partly through S7 (technology)[29] and even RS5. Therefore, they are excluded from our analysis.[30]

The Governance System (GS), in this study, refers to the alternative list of variables, since it matches better with the employed theories. Due to the macro level of analysis, the attributes on policy area, regime type, different types of rules-in-use, and repertoire of norms and strategies, which mainly give us more information regarding the countries' institutional efficiencies, are included in the model. For instance, policy area (GS1) identifies environmental policies that help targeting severe problems within that area. It is worth noting that GS1.1 is the only third-tier variable (subject to the availability of data) that is included in our study. Three important variables of regime type (GS4), rules-in-use (GS6), and repertoire of norms and strategies (GS8) show the quality of formal and informal institutions well.

Property-rights systems, which is located in GS7 in the proposed list, are not rules and, thus, differentiated from GS6 (rules-in-use) by McGinnis & Ostrom (2014a, p. 10); however, Basurto, Gelcich, and Ostrom (2013), used this as another sub-category of GS6. Basically, it defines the relationship between people and their properties, responsibilities and obligations based on the type of goods.[31] However, due to the type of the studied resource, GS7 does not apply in this context. Likewise,

[27] It affects the actors' abilities to interfere into the system's natural process through the physical and technological constructions

[28] It refer to predicting the dynamism of the system (production-consumption pattern) at global and national levels

[29] It measures the technological levels across countries, which potentially indicate people's overall access to the available technologies.

[30] See appendix (Table A. 2-3)

[31] For instance, *(i)* rules for governing private goods (excludable and rival) recognise actors' possession and access to a resource through purchasing, which is also protected by law (constitutional level); *(ii)* rules for governing open-access

due to macro-level of analysis and data limitation, an individual variable for capturing the collective-choice rules (GS6.2)[32] cannot be used. Instead, a proxy variable for all types of the rules (rules-in-use) will be included in the model. Historical continuity (GS10) is also excluded because it is strongly connected to S3 (political stability), as both capture the durability/stability of a political system.

Further, in this study, GS8 is employed as a proxy for informal institutions instead of A6 (norms, trust-reciprocity, and social capital), since it is an encompassing variable that refers to the broad norms and strategies available to all actors engaged in the relevant social and cultural settings (McGinnis & Ostrom, 2014, p. 8: 10). It reflects numerous ways, in which decisions related to the SESs are influenced by culture; while when an actor considers a norm/belief relevant to his or her actions in a particular setting, can be treated as qualities of that actor (A6). On the other hand, informal institutions is a broad term including all norms, beliefs, culture and traditions, which might be better interpreted as a feature of GS and not A.

In the SES framework, the core category of Actors (A) refers to different sets of actors participating in various activities: extraction, production and consumption. Considering the particular attributes of this study, key variables of A3 (history or past experiences) and A7 (knowledge of SES/ mental models) will be directly included in the regressions. Since, they both highlight the importance of the learning process, communication with other actors, and using the past extracting/exploiting experiences for changing current strategies that might have resulted in destruction of resources over the past decades. In this process, having more educated people positively correlated with conserving the environment as more actors are now informed about and aware of their degrading activities and less likely to take such actions.

Also, population (GS3) and a number of relevant actors (A1), though are different from each other and important enough, in this study they refer to the same thing. They highlight a number of people affected by the governance system, and those who consume the resource; however, because of the resource system and the macro level of analysis, they cover all the population within each country. Therefore, as they are strongly connected to demographic trend (S3), both will be excluded. Similarly, important variables of A2 (socioeconomic attributes), and A9 (technologies available) are strongly

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resources (non-excludable and non-rival), in which no effective limitations on the access and use of resources for any actors are established (collective level); *(iii)* rules for governing common-pool resources (non-excludable and rival) where actors' access and use of resources are limited for a certain period of time (operational level).

[32] Collective-choice rules (GS6.2) influence actors' self-organisation. Actors, at the operational level, according to their preferences and incentives, interact to generate direct outcomes. At the collective-choice level (Policy level) officials' policy decisions must comply with a set of collective-choice rules, which affect the structure of situations subsequently, or the participants in policymaking at a constitutional level. At the constitutional level, decisions are about the eligibility criteria for participation in policymaking and the required rules (Ostrom, 2011, p. 11). All enforceable rules affect individuals' incentives, behaviours, and actions directly and shaping the outcomes, therefore, help to achieve order and predictability among them through defining three types of required, prohibited, and permitted actions within different kinds of positions at multiple scales (Ostrom, 2011, p. 17-18).

linked to S1 (economic development) and S7 (technologies), respectively; thus, can be excluded from the analysis.

Although the long-term sustainability of SESs is initially based on the actors or governments to establish required rules, the desired outcome might not be achieved if the implemented rules are not consistent with the attributes of the resource system, resource units, and the norms and traditions adopted by local people (Ostrom, 2009, p. 421). Overall, the core challenge in finding the reasons behind the destruction or sustainability of a resource is to include relationships among useful multi-tiered variables from each linked core category into the analysis. To crack this complexity, one is required to gain knowledge about the variables and their connections (Ostrom, 2009, p. 420). Consequently, depending on the focal level of analysis, the particular research question, and the empirical restrictions, SES's core categories are modified and structured in a way that can fit the research's particular attributes. This highlights the adequacy of such framework for investigating the effect of the quality of institutions within each country to prevent environmental degradation.

Conclusion

Access to natural resources can result in different outcomes for different countries caused by their institutional quality. However, the implications of institutions on environmental performance have not been addressed clearly. In addition, there is an ambiguity in the relationship between institutions and the environment. Moreover, there is a lack of sound institutional foundation in empirical studies about environmental development, especially in resource-rich countries. This research, therefore, tries to estimate and evaluates the significant impacts of both formal and informal institutions on ecological conservation, particularly by looking at different categories of poor, emerging and developed countries possessing different types of natural resources. This will enable us to determine which of the institutions are more important in achieving environmental sustainability by conducting a comparative study among the failed and successful countries.

To that purpose, the Social-Ecological Systems (SESs) framework is taken as the theoretical foundation for this study. Therefore, in this chapter, we tried to clarify how the SES framework can be reformed and improved to fit into this cross-country empirical study focusing on governing open-access resources such as the earth's atmosphere. Using such a framework enables us to identify and recognise the root causes of achieving outcomes of interest. Although, it has been more than a decade since Elinor Ostrom introduced the framework (2007), a major challenge, however, still is opting all effective variables, (rather than elimination), in the special ecological context in order to build rigorous conceptual and empirical basis for linking multiple deeper-level variables.

As tackling the stock of Carbon is the most pressing collective problem confronting all people globally, it needs both government and people' awareness and also a range of actions such as developing national and international policies and treaties, and changing personal transport patterns, recycling households' wastes, and reducing outdoor emissions at a local level to maintain and improve the environmental quality towards the sustainability. Nowadays, due to the significant flow of immigrants (mostly from poor countries to the developed ones), countries' populations become more diverse, and thus, the integration of different ethnicities into hosting societies become much harder than has ever been. Therefore, building an inclusive community where all people from different backgrounds can trust to and cooperate with each other (reciprocate) to achieve collective goals become a major issue for the governments. Therefore, the results of this study could shed some lights on how the level of vertical and horizontal trust can help to mitigate the environmental challenges.

Finally, the findings of this study will be used as a foundation for collecting required data on selected variables, building the quantitative model, and analysing the results. In the next chapter, an empirical approach will be adopted, in which dynamic panel data models of GMM will be used for estimating the institutional effects on environmental performance across all countries during 25 years. The differences in the above empirical specifications between two groups of rich and poor countries in fossil fuels will be explored in the fourth chapter.

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Appendix

The tables below (Tab. A.1-7), list all the variables included in the revised SES framework, regardless of their relevance to the current study. It is organised in the SES's order, in which second-tier variables are grouped by their core categories following by a definition and reason(s) for the inclusion or exclusion of each. Moreover, bold coloured variables are the ones considered as effective enough in the process of self-organisation and ecological outcomes, and thus selected to be included in the quantitative model. As depicted in the tables, the selected 14 second-tier variables, which are shown in table 3 as well, are typed in bold coloured font. The inclusion of 14 variables can potentially cover nine more second-tier variables as they are either fully or moderately linked to the selected variables. They are marked with bold black fonts in the table, while shown "No" in front of their names indicating their exclusions. A summary on the excluded variables is presented below:

- **Broad Social-Economic-Political Settings (S):**

  The category of Settings (S) initially includes seven second-tier variables (as depicted in the table below); however, due to data limitations and irrelevancy, two variables of S4 (other governance systems) and S5 (markets) will be excluded.

Table A. 1. Definitions and explanations for inclusions/exclusions of Social, Economic, and Political Settings' variables drawing on the particular features of this study

Code	Variables by Categories	Y/N?	Definition	Reason for Inclusion/Exclusion
1	**Social, Economic, and Political Settings (S)**			
S1	*Economic development*	*Yes*	*The degree to which a country is productive, industrialised, and economically developed.*	*Since the focal level of analysis is at the country level, such aggregated variables that focus on heterogeneities across countries and time must be incorporated into our model.*
S2	*Demographic trends*	*Yes*	*The population trend, structure, and density of a country.*	
S3	*Political stability*	*Yes*	*Durability of the regime and less inner/outer conflicts in a country; contrary to fragile states.*	
S4	*Other governance systems*	*No*	*N/A*	*No substantial variation across countries/ Data limitation.*
S5	*Markets*	*No*	*N/A*	*Same as above*
S6	*Media organisations*	*Yes*	*The presence of and free access to different types of private and public media in a country.*	*Since the focal level of analysis is at the country level, such aggregated variables that focus on heterogeneities across countries and time must be incorporated into our model.*
S7	*Technology*	*Yes*	*The general level of a country's technological development.*	

Source: McGinnis & Ostrom (2014), and Basurto et al. (2013)

- **Resource Systems (RS):**

  The category of Resource System (RS) initially includes nine second-tier variables (as depicted in the table below); however, considering the specific attributes of the chosen RS and due to data limitations, most of the internal variables within this category will not be included in the analysis. The details are as follows:

1. Sector (RS1), storage characteristics (RS8), and location (RS9) are eliminated from our analysis, since the focus in this study is only on one open-access resource system (earth's atmosphere), within which not much variation is observed across countries.
2. Moreover, equilibrium properties (RS6) is also excluded, because, there is no such market for this resource system globally, thus its equilibrium is not specified.
3. Clarity of boundaries (RS2) and size of the resource system (RS3) are two variables that enable researchers to recognise actors, who are legally permitted to withdraw the resource units, from others. RS2 and RS3 help to sustain the resource and build higher levels of trust within a society (Ostrom, 2012a, p. 25-26; Ostrom, 2007b, p. 18). However, they are withdrawn from the analysis, since the earth's atmosphere is a tremendous open-access resource covering the entire world, within which not size or its capacity, and not even a single distinctive boundary can be clearly defined and measured. Moreover, since the size, as an important variable affecting collective action, is not measurable, people's self-organisation efforts is negatively influenced.

Table A. 2. Definitions and explanations for included/excluded RS's variables drawing on the particular features of this study

Code	Variables by Categories	Y/N?	Definition	Reason for Inclusion/Exclusion
2	***Resource Systems (RS)***			
RS1	*Sector*	*No*	*The focused resource sector is Earth's atmosphere (air quality) and its own unique attributes only. Therefore, we only focus on one sector across countries.*	*No substantial variation across countries/ Data limitation.*
RS2	*Clarity of system boundaries*	*No*	*These two factors enable actors to determine the beginning and ending points, and thus spatial magnitude (area) and capacity (volume) of a resource, which in this case, are totally unspecified and unknown for actors; hence, the sector should be considered as one big system covering the entire world. Thus, the actors' self-organisations will be affected negatively.*	*Since there are no well-defined distinctive boundaries across different countries, making the size of a particular spatial extent unmeasurable, no large variations can be identified to the quality of the air system.*
*RS3**	*Size of resource system*			
	RS3.1 Area			
	RS3.2 Volume			
RS4	***Human-constructed facilities***	***No***	***The degree to which actors are able to interfere in the system (outside of its natural habitat) through their built facilities and technologies. Also, anything that affects the system's natural habitat can affect productivity; thus, RS4 can be, somewhat captured by RS5 and S7.***	***No substantial variation across countries/ Data limitation. However, any disruptions made by actors can somehow be captured by S7 and RS5, which have already been included.***
RS5*	***Productivity of system***	***Yes***	***The resource's natural habitat is affected by the current production-consumption rate in each country and globally. This rate might be changed by the percentage of a land covered in forests and the degree to which a country is emitting pollutions based on producing and consuming primary products using fossil fuels. These will shape the productivity rate, through which actors' self-organisation efforts will be affected.***	***Since the forest ratio and rate of using fossil fuels across countries change the production-consumption rate, it is required to be taken account of in the equation. However, as there is no data available on the system productivity, we should, instead, consider two driving factors above.***
RS6	*Equilibrium properties*	*No*	*There is no market, and thus equilibrium points, for this resource system across countries.*	*No substantial variation across countries/ Data limitation.*
*RS7**	*Predictability of system dynamics*	*No*	***The dynamism of the system depends on the degree to which actors are able to predict or find the production-consumption pattern/trend. The predictability of such a significant open-access resource with its mobile units, while, almost impossible, is somewhat dependent on the technologies (S7) available and the driving factors of production-consumption rate (S5).***	***No substantial variation across countries/ Data limitation. However, to some extent, it can be explained by S7 and RS5, which have already been considered in the equation.***

RS8	*Storage characteristics*	*No*	*The degree to which the number of resource units or pollution can be stored/ trapped in it until harvested/released. Natural or artificial storage capacity, generally, may differ across resource systems, units, and countries; however, in this case, it does not vary much.*	*No substantial variation across countries/ Data limitation.*
RS9	*Location*	*No*	*Refers to the temporal and spatial extent where the resource and its units can be found by harvesters. But, access to the studied resource is open to any group of actors from anywhere.*	*Same as above*

Source: McGinnis & Ostrom (2014), and Basurto et al. (2013)

- **Resource Units (RU):**

  The category of Resource Unit (RU) includes seven second-tier variables (as depicted in the table below); however, since this study focuses on a type of a public good as an RS (earth's atmosphere) that cannot be divided into units by its definition, it must be treated as a whole one aggregated subcomponents. Therefore, the presence of any attributes related to RUs listed in the table will not make any difference in the analysis as they do not vary considerably across countries, thus, must be excluded. So, none of the RUs' internal variables will be considered in this study.

Table A. 3. Definitions and explanations for included/excluded RUs' variables drawing on the particular features of this study

Code	Variables by Categories	Y/N?	Definition	Reason for Inclusion/Exclusion
3	***Resource Units (RU)***			
*RU1**	*Resource unit mobility*	*No*	*Resource units can be either stationary or mobile, accordingly, for each of which different governing rules will be needed. In this study, units are mobile moving spatially and temporally, thus, negatively associated with actors' self-organisation efforts.*	*No substantial variation across countries/ Data limitation.*
	RU1.1 Mobile units			
RU2	*Growth or replacement rate*	*No*	*Refers to absolute or relative changes in quantities (reserves) of RUs over time. However, as air system is a renewable RS, the replacement rate stays the same, unless it is disrupted, which in this case changes can be captured by the proxies used in RS5 (productivity of the system).*	*Same as above*
RU3	*Interaction among resource units*	*No*	*The units' interaction is neutral unless it is disrupted by the emitted particulates.*	*Same as above*
RU4	*Economic value*	*No*	*It can be identified by subsistence and market values. However, here, they are impossible to be measured as RS is an open-access resource; also there is no market for enormously valued units, on the other.*	*Same as above*
RU5	*Number of units*	*No*	*A number of units are indefinite and cannot be specified.*	*Same as above*
RU6	*Distinctive characteristics*	*No*	*Refers to particular natural and artificial markings in the appearance of units or/and in actors' behavioural patterns toward using them. In the air system, all units are homogenous.*	*Same as above*
RU7	*Spatial and temporal distribution*	*No*	*Refers to the distribution of units that can be either variable (random) or stable across areas in a certain time. Accordingly, mobile air units are distributed variably across all countries.*	*Same as above*

Source: McGinnis & Ostrom (2014), and Basurto et al. (2013)

- **Governance System (GS):**

The category of Governance System (GS) initially includes eight second-tier variables; however, in this study, GS refers to the alternative list of variables (as presented in the table below). It includes 10 different attributes mainly on the institutional system's efficiency including regime type, different types of rules, and a repertoire of norms and strategies, as it fits the theory used in this study better. The details on the excluded variables are available as follows:

1. Geographic scale of governance system (GS2), population (GS3), and rule-making organisations (GS5) are important variables in the process preventing environmental degradation; however, due to the focal level of analysis, their inclusions will not make substantial variations across countries. In fact, GS2 and GS3 are designed for defining the scale of the GS, in which they are considered and affected by that governance policy. However, in this research, unlike case studies, settings can capture the macro scale of a country. Also, there might be strong linkages between them and other variables, like GS5, which its effects are somewhat taken by GS4 (regime type), while GS3 already captured by S2 (demographic trend).
2. Further, as actors in the SES framework are either collective or individual agent, the rules that define the responsibilities of agents should then be included as the feature of governance system (McGinnis & Ostrom, 2014, p. 8-9). Hence, the connection between the proposed GS5 and GS3 (organisations and population) can be enhanced through different modes of network structure (GS9) consisting of centrality, modularity, connectivity, and a number of levels (McGinnis & Ostrom, 2014, p. 10). However, network structure (GS9) will be eliminated as well, because of the focal level of analysis, its inclusion will not make substantial variations across countries. Besides, network structure, by definition, links GS3 (population) to GS5 (organisation); as both are excluded, it does not make sense to include their mode of connections.

Table A. 4. Definitions and explanations for included/excluded GSs' variables drawing on the particular features of this study

Code	Variables by Categories	Y/N?	Definition	Reason for Inclusion/Exclusion
Governance System (GS)				
GS1	*Policy area*	*Yes*	*It is exactly like the resource sector (RS1) and includes rules and policies related to a specific area for targeting and solving severe problems within that area, e.g. social, environmental, health and economic policies, etc. In this study, environmental policies are of interest.*	***Governments adopting policies aiming at managing open-access resources like air pollutions will be captured by an appropriate variable, subject to availability of reliable data.***
GS1.1	***Environmental Policies***			
GS2	*Geographic scale of governance system*	*No*	*Refers to the physical geographic range that is affected by the ruling system and its adopted policies. In this cross-country study, rules and policies affect each country's entire size.*	*No substantial variation across countries/ Data limitation.*
GS3	***Population***	***No***	***Refers to the population of actors that are affected by the ruling system and its adopted policies. As all actors have access to the RS, entire population in each country are affected.***	***Any changes in this factor have completely been captured by the S2 (demographic trend).***
GS4	*Regime type*	***Yes***	***Political system is mainly divided into two main categories. Autocratic regime, in which not elected politicians have the authority to make decisions for the entire population; and democratic, in which politicians are elected by the nation through free election/voting. Since each system implements different administrative policies, based on its diverse rules and laws, its outcomes would be extremely different from one another across countries.***	***Since it indicates the overall quality of formal institutions across countries, it must be included in the model.***
GS4.1	*Democratic (polycentric)*			
GS4.2	***Autocratic (monocentric)***			

GS5	Rule-making organisations	No	Refers to different types of organisations (governmental, private, voluntary, community-based & hybrid) at multiple scales that are responsible for making rules for the individual- and collective-agent actors to facilitate formal structured interactions among them.	No substantial variation across countries/ Data limitation.
GS6	Rules-in-use	Yes	Refers to all functional formal and informal rules that shape humans' behaviours and interactions that are divided into three types, within which all types of interactions are being monitored and sanctioned by specific rules (monitoring rules are implicitly built-in).	Due to the macro level of analysis, and the fact that these types of rules are inter-connected—practical and operational decisions are constrained by collective rules, which itself can be changed by constitutional ones—we will include an all-inclusive variable that can capture changes in the broad variable of rules-in-use to evaluate formal institutions in depth.
GS6.1	Operational-choice rules		Practical decisions made by actors who are legally allowed to implement rules. At this level, actors interact based on their preferences and incentives, to generate direct outcomes.	
GS6.2	Collective-choice rules*		Refers to rules limiting both citizens and officials in doing operational activities–a process through which institutions are built–which might be reformed by constitutional rules.	
GS6.3	Constitutional-choice rules		Refers to rules and decisions determining who are authorised/allowed to (eligibility criteria) participate in making operational rules (rule- and policy-making process).	
GS7	Property-rights system	No	Rules determining the relationship and responsibilities of actors in regards to their possessions, divided into four types of private, public, common, and mixed based on the type of goods. It shows the quality of economic institutions, which can be considered as a sub-category of GS6 as well.	As this study focuses on an open-access resource, in which all have equal access to, GS7 is not relevant and can be excluded. Besides, it is strongly linked to & somewhat captured by GS6.
GS8	Repertoire of norms and strategies	Yes	Reflects numerous ways, in which decisions related to SESs are influenced by culture. It is an encompassing term referring to all the norms or shared strategies available for the use of actors within the relevant social and cultural settings. While when an actor considers a norm/belief relevant to his/her actions in a particular setting, it can be treated as attributes of that actor (A6). Hence, GS8 might be best interpreted as attributes of the GS.	Since informal institutions is a broad term including norms, beliefs, culture, trust and traditions of a society; it might be best indicated by the encompassing variable of GS8, which includes the entire norms. Otherwise, if a variable indicates actors' attributes, it is best interpreted as Actors' attributes.
GS9	Network structure	No	Refers to the link between GS5 and GS3 (population and organisation) that can be facilitated through different modes of network structure: centrality, modularity, and connectivity.	No substantial variation across countries/ Data limitation.
GS10	Historical continuity	No	As governance systems have deep historical origins, distinguishing between stable systems and recent ones, enables us to differentiate their behaviours toward ecological conservation.	Stability or fragility of a state has already been captured by S3 (political stability), thus excluded from the analysis.

Source: McGinnis & Ostrom (2014), and Basurto et al. (2013)

- **Actors (A):**
  In the SES framework, the core category of Users (U) changed to Actors (A), since there are different sets of actors participating in different types of activities. However, the former label was not inclusive enough to include individuals' behaviours who are not direct consumers of products of the resource system. Thus, the category "users" is now included as a sub-category of actors. With respect to the studied resource system (earth's atmosphere) and the focal level of analysis, most of the internal variables will be excluded from our analysis:

1. A4 (location) and A5 (leadership/entrepreneurship) are also excluded because of data limitation and having not much variation across countries.

2. Likewise, A8 (importance of the resource), though is an effective factor in the process of alleviating collective-action problem, must be excluded as it cannot be measured because there is no market on such a valuable resource system. However, due to the inherent attributes of such open access resources, actors cannot be effectively limited; hence the RS become extensively polluted, which is then results in global warming.
3. A6 (norms, trust-reciprocity, and social capital) refers to the level of interpersonal trust and social capital, thus must be included in our regression. Because it helps to solve and alleviate the collective-action problem. However, informal institutions is an encompassing concept, which refers to all norms or shared strategies available for all actors within a relevant socio-cultural context. While, when an actor considers a norm/belief relevant to his or her actions in a particular context, it can be treated as attributes of that actor. Therefore, instead of using this variable, GS8 might be best representing informal institutions as a whole (A6 is replaced with GS8).

Table A. 5. Definitions and explanations for included/excluded As' variables drawing on the particular features of this study

Code	Variables by Categories	Y/N?	Definition	Reason for Inclusion/Exclusion
5	*Actors (A)*			
*A1**	*Number of relevant actors*	*No*	*Number of actors relating to harvesting the resource system.*	*S3 has already captured any variations in this part.*
A2	*Socioeconomic attributes*	*No*	*Actors' economic and socio-cultural conditions that affect resource dynamics.*	*It is excluded because its effects can also be captured by S1.*
A3	*History or past experiences*	*Yes*	*It refers to the historical pattern of usage or past experiences of withdrawing resource units resulting from the interactions of the actor's behaviour and resource biophysical characteristics.*	*Its effects can be considered via including a lagged version of the previous environmental performance in our model.*
A4	*Location*	*No*	*Refers to the physical location of the actors with respect to the resource being extracted.*	*No substantial variation across countries/ Data limitation.*
*A5**	*Leadership/Entrepreneurship*	*No*	*Actors with leadership capabilities that help to organise their peers to pursue collective actions*	*Same as above*
*A6**	*Norms (trust-reciprocity)/ Social capital*	*No*	*Social capital indicates how tight the bond is among actors within a society, and trust is to what degree they can rely on each other for supporting agreements among themselves, even if it is not their current interests. Also, reciprocity refers to the cooperative response to an action taken previously by other members of the society. Higher levels of A6 are associated with the successful collective action, hence, should be considered in the model.*	*This variable is strongly connected to GS8. However, as GS8 is a better variable in representing informal institutions, it is replaced with A6, and thus excluded from the analysis.*
*A7**	*Knowledge of SES/Mental models*	*Yes*	*A process within which actors learn characteristics of resources and understand its dynamics, which affect the state of the resource and result in better efficiency. It is an important factor that influences people's self-organisation ability.*	*Since the level of education affects the state of resources, a variable that can capture its variations across countries must be included in the equation.*
*A8**	*Importance of resource (dependence)*	*No*	*The degree to which people's lives are dependent on the resource system, mainly financially (as a source of income) and culturally (as a source of values). It is an important factor, which affects the self-organisation abilities of actors toward the resource sustainability or maintenance.*	*No substantial variation across countries/ Data limitation.*
A9	*Technologies available*	*No*	*The degree to which technologies used in the process of harvesting are modern and also widely available for people within a society for using the resource more efficiently.*	*Any change in this factor can be captured by S9 (technology), hence excluded from the analysis.*

Source: McGinnis & Ostrom (2014), and Basurto et al. (2013)

- **Focal Action Situations: Interactions (I) and Outcomes (O)**

  The focal action situation is comprised of two parts: *(i)* interactions and *(ii)* outcome. So far, 10 interactions have been observed in the SES framework that is contributing to three types of ecological and social outcomes along with externalities to other SESs. Among all interactions, self-organising activities (I7) are mentioned as the most important one, thus will be studied in this research. Also, here, only environmental outcomes (O2) are of interest, thus, the rest of the variables are excluded accordingly.

Table A. 6. Definitions and explanations for included/excluded Focal Action Situations' variables drawing on the particular features of this study

Code	Variables by Categories	Y/ N?	Definition	Reason for Inclusion/Exclusion
6	***Interactions (I)***			
I1	*Harvesting*	*No*	*Refers to the harvesting/withdrawing level of diverse actors at multiple levels. In this study, it cannot be determined as we are focusing on the earth's atmosphere.*	*Such interaction is not of interest/considered within this study.*
I2	*Information sharing*	*No*	*It is an important interaction as it facilitates the learning process. Any tools that help to share and distribute information among diverse actors contribute positively to outcomes.*	*Same as above*
I3	*Deliberation processes*	*No*	*The degree to which a governance system is less centric, the likely the deliberation processes take place among actors. More negotiation generally result in fewer conflicts.*	*Same as above*
I4	*Conflicts*	*No*	*Conflicts among actors occur due to the lack of communication among actors, appropriate laws, and external authorities for practising monitoring and sanctioning processes.*	*Same as above*
I5	*Investment activities*	*No*	*Any types of investment leading to physical and social capitals that improves the status quo.*	*Same as above*
I6	*Lobbying activities*	*No*	*Depending on the governance system/type of the regime, the possibility of taking lobbying activates by diverse actors may affect the system either positively or negatively.*	*Same as above*
I7	***Self-organising activities***	***Yes***	***Refers to actors who invest their time and energy in conserving the environment; and depends on 10 second-tier variables (marked with asterisks), that can be mainly divided into three parts of formal and informal institutions and resource's attributes.***	***Out of 10 variables, only 3 of them (RS5, GS6, A7) directly, and another 3 (RS7, A1, A6) indirectly-through their strong links to other selected variables- are included in the model.***
I8	*Networking activities*	*No*	*Actors' networking with each other and different types of organisations results in better mutual understandings and a higher level of trust, leading to positive outcomes.*	*Such interaction is not of interest/considered within this study.*
I9	*Monitoring activities*	*No*	*Refers to rules and activities designated for monitoring diverse actor's behaviours to oblige them following the rules, leading to lowering deregulated harvesting level and conflicts.*	*Same as above*
I10	*Evaluative activities*	*No*	*Refers to the feedbacks from the current operated SES that received at later times, which can be used as criteria for evaluating and improving the system.*	*Same as above*
7	***Outcomes (O)***			
O1	*Social performance measure*	*No*	*It includes indicators measuring a social aspect of development.*	*Such outcomes is not of interest/considered within this study.*
O2	***Ecological performance measures***	***Yes***	***It includes indicators measuring an environmental aspect of development.***	***Ecological outcomes in this study are examined mainly through the quality of air across countries.***
O3	*Externalities to other SESs*	*No*	*It includes indicators that take account of any externalities that the studied SES might result in other systems, and not the outcome of the studied SES directly.*	*Such outcome is not of interest/considered within this study.*

Source: McGinnis & Ostrom (2014), and Basurto et al. (2013)

- **Related Ecosystems (ECO):**

  The social-ecological systems are inter-linked, within which the sustainability or destruction of one ecosystem may affect the other ones. The category of Related Ecosystems (ECO) also highlights three important interlinkages (as depicted in the table below). As we are working on an encompassing resource system that directly affects a number of ecosystems and species, above argument also holds here; however, due to the empirical restrictions, these flows cannot be considered within this study.

Table A. 7. Definitions and explanations for included/excluded ECOs' variables drawing on the particular features of this study

Code	Variables by Categories	Y/N?	Definition	Reason for Inclusion/Exclusion
8	***Related Ecosystems (ECO)***			
ECO1	*Climate patterns*	*No*	*Resulted global warming from intensive GHGs concentrations contributes to climate change.*	*Such ecosystem is not of interest/considered within this study.*
ECO2	*Pollution patterns*	*No*	*Consistent pollutions in a specific area and point of time resulted from the other pollutions.*	*Same as above*
ECO3	*Flows into and out of focal SES*	*No*	*Studied SES might affect/be affected by other SESs, leading to positive/negative in/outflows from.*	*Same as above*

Source: McGinnis & Ostrom (2014), and Basurto et al. (2013)