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Designing Effective City-to-city Transnational Collaboration for Climate Mitigation: Network Element and Network Centrality

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Abstract— With the emerging issues of the climate change, the international society has formed international coordination and cooperation, such as the IPCC and the UNFCCC, permitting to share climate-related information and discuss about strategic solutions of climate mitigation. In this context, countries have agreed on reducing a certain amount of carbon dioxide through the shift from fossil fuel to renewable energy, transitioning conventional energy system to be cleaner and sustainable within their geographical boundaries. Knowing that international issues such as climate change require coordination problem-solving strategy to increase its impact and synergy effects, cities, countries and regions have formed urban cooperative networks and coordination to increase synergies, share technical knowledge and engender climate change mitigation and adaptation impacts. The following study aims to investigate the C2C (city-to-city) climate network effectiveness in the presence and absence of network elements including (i) a specific linkage and (ii) network externality elements. In addition, network characteristics of the identified international C2C will be assessed through the result of their (i) eigenvector centrality and (ii) connectivity degree to ultimately assess the relative importance of network characteristics of highly effective transnational C2C networks, along with presumable geographical implications.

Keywords— Multilateral C2C, transnational network for climate mitigation, network elements, eigenvector centrality

I. Introduction

Established in 1988, the Intergovernmental Panel on Climate Change (IPCC) formed a platform for agreement, information delivery and networking among scientists and policy makers. Its establishment was followed by the creation of the UNFCCC (United Nations Framework Convention on Climate Change) (1992), followed by Kyoto Protocol (1997), and Paris agreement in 2015 that opened the door for further coordination and cooperation between the cities, countries and regions.

Within the national boundaries, countries are encouraging corporations to promote more sustainable technologies contributing to each country's mitigation target goals by providing diverse incentives. This whole set of energy transition from centralized to decentralized, and from non-renewable to renewable has transformed the conventional energy system to a new energy system in transition. Beyond the national boundary, countries are forming cooperation and coordination **[6]** with other countries sharing similar goals, to increase their mitigation synergies and to respond to their national target **[11] [12]**, by forming networks between cities, countries and regions. In this term, transnational networks for climate change and clean energy has more than doubled, creating platforms of technical information exchange, research and networking.

Meanwhile, increasing numbers of transnational networks doesn't necessary imply its effectiveness. Sustainable networks require prior consideration to sustain and create synergies through a concise design of their networks. Previous research **[9]** analyzed functions and activities existing within the city-to-city (C2C) networks to see its effectiveness through means of activities. The research suggested that climate networks with advanced functions such as lobbying, research, climate plans, and monitoring are likely to actively engage countries and regions in the collaboration, whereas the C2C only focusing on shallow activities such as networking and information sharing find difficulties in maintaining their networks **[9]**.

In a similar context, the following research will categorize C2Cs into networks having or not city network elements (specific linkage and network externality element) mentioned by Capello, R., 2000, which is considered as essential factors to create synergies of city networks. Through the categorization, it aims to assess its effectiveness according to the difference of current activities means collected between 2017 and 2019 (T-test). Secondly, it aims to visualize the existing transnational city-to-city networks and identify topological characteristics including the importance of their relative nodes through the eigenvector centrality value. In overall, the research aims to assess effectiveness and sustainability of the C2C climate networks, while assessing their network elements and characteristics.

II. Previous Research and Research question

A. *Collaboration Structure: Coordination and Cooperation*

Once a common issue is recognized in the international society, countries form collaborations from coordination to cooperation, depending on the different variables that affect prospects for collaboration **[7]**. According to Keohane R**.,** the structure of coordination and cooperation can be divided into four distinct categories, defined by agreements that are self-enforcing (coordination is sufficient) or not (cooperation is required) and potential joint gains that are high or low. Self-enforcing collaborations are therefore classified into cooperation. Cooperation that has high potential of joint gains are classified as cooperation with high rewards but with dangers of defection that rise with the depth of cooperation **[7]**. Those with low potential of joint gains have little incentive to seek to cooperate despite of the shallowness of cooperation that limits the danger of defection **[7]**. On the other hand, collaborations that are not self-enforcing are classified as coordination with low potentials of gains can make easy coordination, but with very limited levels of mutual gains.

B. *City-to-city network, effective activities and functions*

In "Mapping city-to-city networks for climate change action: Geographic bases, link modalities, functions, and activity" **[9]** the authors presented C2C (city-to-city) climate action networks that were classified into geographical bases, linking modalities (multilateral and institution-led) and into functions of the networks (information exchange, networking, lobbying, funding, research, standards, etc.) **[9]**. Research suggests that climate networks with advanced functions (lobbying, research, climate plans, and monitoring) are likely to actively engage relevant countries in climate change collaborations, whereas the C2C only with activities focusing on functions such as networking and information sharing rather lessened the existing networks. The paper suggests that advanced design of C2C networks with proactive activities such as research and monitoring functions, will be necessary for long-term and sustainable networks.

C. *Identification of International C2C networks and research questions*

Previous research mentioned the nature of collaboration underlining socio-economic and political effects of shallow and deep cooperation and coordination, from which countries' participatory motivations are described depending on economic incentives or institutional enforcements **[7]**. Other researches delineate success factors of a sustainable C2C, such as geographical, political, economic characteristics of the participating cities and/or regions. However, only few studies describe network elements and network characteristics of a highly effective C2C networks. In this research, regional and global multilateral collaborations are identified as transnational C2C climate networks (Table 1.). Most of the identified C networks are already described by previous researchers, including (i) EUROCITIEs, (ii) Climate Alliance of European Cities, (iii) Energy Cities, (iv) Western Climate Initiatives, etc. For this research, Climate change adaptation networks are excluded for analysis such as Delta Alliance and Connecting Delta City, and only climate mitigation-related networks are assessed. Additionally, recently established networks, such as International Urban Cooperation (IUC) and Climate Adapt, are updated. In sum, the following study aims to answer to the following questions:

- Are the city network elements mentioned by Capello, R., necessary to bring effective C2C networks? Does the presence of network elements (specific target and network externality elements such as creation of new jobs) affect the overall effectiveness (activeness) of the network?

-What are the network characteristics of a proactive C2C transnational networks?

III. Research Methodology and Data

The method applied to assess the effectiveness of the listed transnational C2C climate networks is the T-test statistics methods, that compares means of activities for networks having or not a network elements: (i) specific linkage (such as SDG goal) and (ii) network externality elements (such as conducted projects, new job creations, etc.). The second methodology used to assess network characteristics of global C2Cs are (i) eigenvector centrality an (ii) connectivity degree, which aims to visualize and assess networks characteristics, which nodes are aggregated into country level. The eigenvector centrality is expected to provide the relative importance of each node within each C2C network, while the connectivity degree delineates the "degree" of which each nodes are connected to other nodes.

A. *Methodology and Equations*

- ***T-test (t)***= $t = \frac{\bar{X}_1 - \bar{X}_2}{S_{\bar{X}_1 - \bar{X}_2}}$ ……………………………………..*(1)*

where $S_{\bar{X}_1 - \bar{X}_2} = \sqrt{\left(\frac{N_1 S_1^2 + N_2 S_2^2}{N_1 + N_2 - 2}\right)\left(\frac{N_1 + N_2}{N_1 N_2}\right)}$

and $S_1^2 = \frac{\sum X_1^2}{N_1} - \bar{X}_1^2$; $S_2^2 = \frac{\sum X_2^2}{N_2} - \bar{X}_2^2$

- ***Network centrality****: Eigenvector, centrality degree*

(1) Eigenvector centrality is used to assess C2C participatory country's importance in the network. It is defined with the largest eigenvalue of the matrix A **[3], [8]**, represented as $A_x = \lambda_x$ in a matrix, or as:

$\lambda x_i = \sum_j a_{ij} x_j$, or $x_i = \frac{1}{\lambda} \sum_j a_{ij} x_j$ for each node i…….*(2)*

(2) Freeman's general formula (equation c) is used to assess the overall connectivity of networks:

$$c = \frac{\sum_i^g [c(n^*) - c(n_i)]}{max \sum_i^g [c(n^*) - c(n_i)]} = \frac{\sum_i^g [c(n^*) - c(n_i)]}{[(g-1)(g-2)]} \text{ ....} (3)$$

where, g= number of nodes,
$c(n^*)$= Centrality degree of the node with maximum nodal connection
$c(n_i)$ = Centrality of each node

B. *Data*

TABLE I. C2C Network Analysis Data: Identification of (i) Bi-lateral and Multi-lateral, (ii) Regional and global Networks

ID	Network	Processed data from website *Node/ Connectivity*	Geographical Extent
C2C1	International Urban Cooperation	A	Global
C2C2	C40	B	Global
C2C3	World Mayor's Council on Climate change	B	Global
C2C4	International Solar Cities	B	Global
C2C5	Climate Adapt		Regional (EU)
C2C6	EUROCITIES		Regional (EU)
C2C7	Climate Alliance		Regional (EU)
C2C8	Energy Cities		Regional (EU)
C2C9	Western Climate Initiative		Regional

Link/ Connectivity: **A**=City-co-city; **B**= Assumed all cities, with a mitigation target goal, are networked

TABLE II. DATA FOR T-TEST: CATEGORIZATION OF (I) SPECIFIC NETOWRK ELEMENTS, (II) EXTERNALITY ELEMENTS

ID	Conducted Activities based on website	Specific target elements		Network Externality Element		Connected to other C2C (2018-2019)	
		Yes	*No*	*Yes*	*No*	*Yes*	*No*
C2C1	Bi-monthly webinars, funding, case study & plan	✓		✓			✓
C2C2	Programs, funding, Research, Networking	✓		✓		(1)	
C2C3	Meeting & Advocacy		✓		✓	(2)	
C2C4	Meeting & Conference		✓		✓		✓
C2C5	Knowledge Projects, develop Tools, Research & publications, lobbying	✓		✓		(3)	
C2C6	Publication, conference, case study, projects, Job creation, webinars, lobbying	✓		✓			✓
C2C7	Project, tools & methods develop, advocacy, campaigns, conference	✓		✓			✓
C2C8	Workshop, Webinar, Project, annual conference, research	✓		✓			✓
C2C9	Program Initiatives, budget & tax filing	✓			✓		✓
Accumulated Sum		7	2	6	3	3	6

(1) Complementary connected to Delta Cities; (2) ICLEI;
(3) Complementary to Covenant of Mayors

C. *Description of transnational C2C climate networks*

- *The International Urban Cooperation (IUC)*

The International Urban Cooperation (IUC) which has both the characteristics of coordination and cooperation was established by the European Union, forming program activities supporting the achievement of bilateral policy objectives on diverse sectors and the mayor's agreement on urban development and climate change defined by the Urban Agenda, Sustainable Development goals, and the Paris Agreement. (IUC, 2018)[1] It is comprised of three major components, where the first one seeks to achieve a target goal of diverse sectors, including housing, energy, water, etc. within its network, through a cooperative characteristic. In the following case study, only the first component of IUC network is analysed with the energy sector. This represents a cooperation network between cities aggregated into countries for the energy sector. In the network analysis, nodes are represented by countries (weighted according to the number of linkage and the number of C2C networks within the country) participating in the energy sector network within IUC network. Edges are represented according to the number of set target goals that were selected among 17 Sustainable development goals (SDG 7: clean energy).

- *The C40*

The C40 connects 84 cities around the world, with specific target initiatives such as energy, transportation, etc. Cities participating in the C40 network are especially ambitious in working and collaborating together to act on climate related issues including energy sectors. Countries participating in the C40 network for the energy sector are from all continents totaling a number of 23 and 40 cities.

- *World Mayor's Council on Climate change*

Founded in 2005 by the Mayor of Kyoto, the World Mayor's Council on Climate change comprises 80 members around the globe. This network in slightly different from the previous two networks since it does not have specific target elements like IUC and C40. The main purpose of the network is to encourage mayors (local government) to participate in climate change related coordination with two distinctive activities: advocacy and networking. For this coordination network, network nodes are represented as participating countries and the weighed edges according to the number of cities within member countries. The represented edges therefore represent "assumed networks" between cities and countries.

- *International Solar Cities (ISCI)*

The International Solar Cities Initiatives (ISCI) was first founded in 2003. It is a non-profit network and mainly aims to promote new urban policies reducing per capita greenhouse gas emissions, permitting to promote climate sustainability. Though its purpose is clear, no clear target and activities are proposed, leading to a simple conference and meetings for networking without any direct external effects. Member cities participating in the networks include Oxford, Daezhou, Daegu, Adelaide and Buenosaires.

IV. RESEARCH RESULTS

A. *Research Result: network effectiveness (proactiveness) in the presence and absence of the network elements*

The presence of specific network elements was identified with the presence of specific network targets such as "energy sectors", "linkage with SDG 7" etc. Similarly, the presence of network externality elements was categorized with the presence of activities bringing proactive activities, including economic assets, categorized as "advanced functions" (projects, job postings, etc.) identified from Lee, T., et al., 2018.

As the result from table 3. delineates, the t-test result shows a net difference (i) between networks having specific network elements or not, and (ii) between networks having externality elements or not. The result shows two-tailed t-test result of -3.265 between networks having specific network elements or not and -3.416 between networks having externality elements or not. The result implies that networks (i) having specific linkage and (ii) activities bringing network externality tended to be proactive than those lacking these network elements.

[1] International Urban Cooperation: http://www.iuc.eu/global-covenant/

TABLE III. T-TEST RESTUL OF TRANSNATIONAL CLIMATE C2C

	Specific target elements (2017-2019)		Network Externality Element (2017-2019)		Active Status of the Network
	Yes	*No*	*Yes*	*No*	
C2C1- International Urban Cooperation (Energy sector)	3		3		O
C2C2- The C40 (Energy Sector)	4		4		O
C2C3- The World Mayor's Council on Climate change		2		2	X
C2C4- International Solar Cities		1		1	X
C2C5- Climate Adapt	4		4		O
C2C6- EUROCITIES	6		6		O
C2C7- Climate Alliance	5		5		O
C2C8- Energy Cities	5		5		O
C2C9- Western Climate Initiative	3			3	O
T-test	**-3.265 ****		**-3.416 ****		

** Significant with p=0.10 (Two-tailed)

B. *Network characteristics of "global" transnational C2C networks: (i) connectivity and (ii) eigenvector centrality*

Figure 1, 2, 3 and 4 in the appendix represents network connectivity visualization of IUC (C2C1), C40 (C2C2), the World Mayor's Council (C2C3) and ISCI network (C2C4) respectively. Nodes are represented through countries connected with weighted edges according to the number of cities, weighed themselves according to the number of target links. For instance, in the IUC network, Italy has a weighed edge of 2 with China, meaning that two cities between China and Italy are cooperating for cleaner energy and climate mitigation.

The following graphs delineate the eigenvector centrality values of each network, where each point represent the eigenvector centrality value of each node (country). The value represents the importance of each node's importance within each distinctive C2C climate network. For instance, in IUC, Italy is positioned at the first rank, followed by China and Japan. This rank represents the hierarchy within the network, representing as well the importance of each node within the overall C2C network.

1. The International Urban Cooperation (IUC)

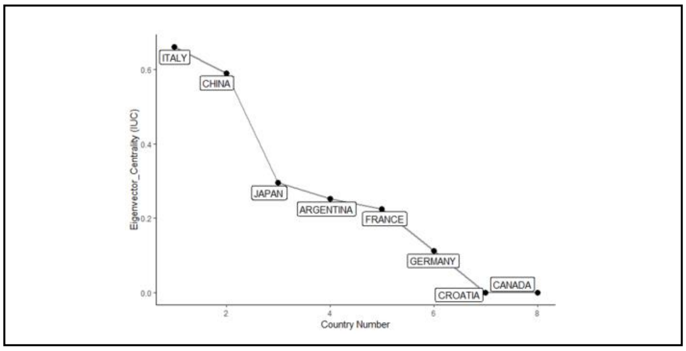

Fig. 1. Eigenvalue centrality graph of IUC network

2. The C40

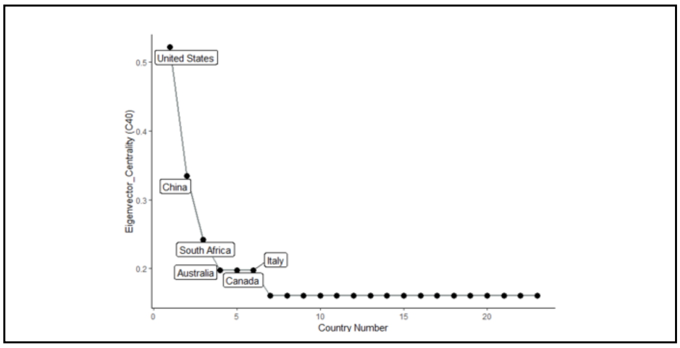

Fig. 2. Eigenvalue centrality graph of C40 network

3. The World Mayor's Council

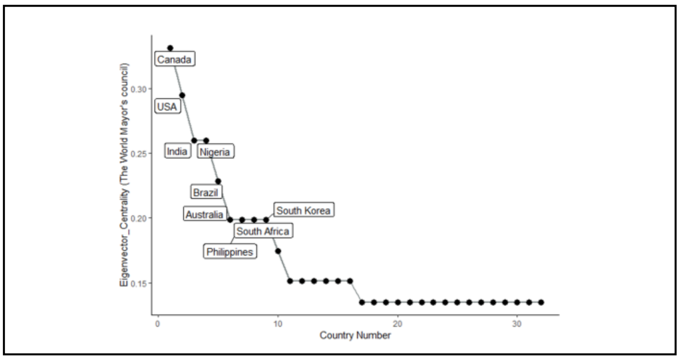

Fig. 3. Eigenvalue centrality of World Mayor's Council on Climate Change

4. International Solar Cities(ISCI)

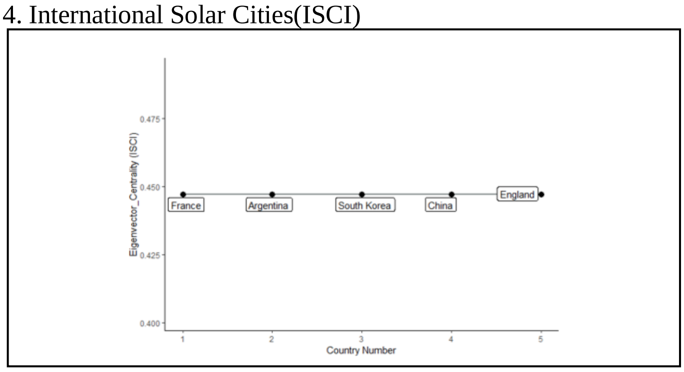

Fig. 4. Eigenvalue centrality graph of ISCI network

Table 4. represents a summary of the analysis result, where the "network's effectiveness" is represented based on website updates and proactive status, divided into three categories:

- S-Strong (highly proactive)
- M- Medium (proactive)
- W-Weak (not active)

The proactive status is based on information collected from each C2C website, specified in Table 3.

Mean of connectivity represents the mean of degree connectivity for each network. In other words, the mean of connectivity represents the mean of connectivity value of each node within each distinctive C2C climate network.

Highest eigenvector value describes the hierarchical structure and importance of each node within the relevant network (the information centrality is proportional to the eigenvector value, meaning that higher position in the hierarchy leads to the higher exposure to information within the network).

TABLE IV. (I) CONNECTIVITY, (II) EIGENVECTOR CENTRALITY, (III) CONNECTIVITY TO OTHER NETWORK, (IV) SPECIFIC LINK TARGET RESULTS

	Active Status			**Specific Link target**		**Mean Degree centrality**	**Highest Eigen-vector Centrality**	**Connec-tivity to other network(s)**
	S	*M*	*W*	*Y*	*N*			
C2C1		✓		✓		0.107	0.660556	No
C2C2	✓			✓		1.739	0.521137	Yes
C2C3			✓		✓	2.469	0.331378	Yes
C2C4			✓		✓	1	0.447214	No

S= strong**; M**= medium**; W**=weak
C2C1= IUC; **C2C2**=C40; **C2C3**= World Mayor's Council; **C2C4**= ISCI

In overall, research shows that C2C networks having a hierarchical value of eigenvector centrality tend to be more effective. The IUC describes the highest eigenvector value with 0.66 among all identified transnational C2Cs, while the means of connectivity stays the lowest. This is because IUC's connectivity analysis is performed base on specific linkage, from "city pairing" data with a specific linkage element (SDG 7), while others are performed based on "all-cities connection assumed" paring, eventually resulting a higher value of connectivity.

Meanwhile, the C40 (C2C2) network is categorized as the most proactive network among the identified transnational C2C climate networks. It has the second highest eigenvector value and the second highest degree connectivity with a specific linkage target (network element), identified as mitigation goal (renewable energy sector).

The World Mayor's Council network for climate change (C2C3) and the International Solar Cities (ISCI) (C2C4) are the least proactive networks classified among the transnational C2C climate networks. Both show inactiveness status, leading to a failure of network engagement. With the lowest eigenvector values and lack of specific network elements, the ISCI delineates a typical shallow coordination network as delineated by Keohane, R., lacking effective joint action, and therefore leading to network collaboration failure. As delineated in "Cooperation and discord in global climate policy" **[7]** effective mitigation of climate change collaboration for C2C requires deep international cooperation despite of potentials of elusiveness. Hierarchy among networks (presence of hierarchical eigenvector centrality) implies active engagement by certain countries whether to seek benefits or not, with strong willingness for participation, which eventually leads the overall C2C network with higher activity outputs and effectiveness.

In terms of C2C connection to other C2C networks, C2C2 and C2C3 are connected to "Connecting Delta Cities" and "ICLEI" respectively. C2C2 demonstrates highly effective activity outputs while C2C3 does not. This difference can be partially explained from "the discovery of areas of discord where additional collaboration" is required **[7].** C2C2 (C40) is therefore created through unsatisfactory shallow coordination of "connecting delta cities", resulting a highly effective network cooperation with specific collaboration goals. On the other hand, the C2C3 (World Mayor's Council) show a typical shallow-coordination network from which deeper cooperation is derived (ICLEI) with specific activities along with more specific target goals. Finally, the degree of connectivity does not seem to highly affect the overall effectiveness of the network, given the fact that edges for C2C3 and C2C4 where arbitrary linked with all participant countries (due to the lack of specific linkage elements).

V. IMPLICATIONS

A. Network elements for effective networks

The study shows that network elements (specific network target and the presence of network elements bringing network externality) bring effective result for transnational C2C networks **[4]**. In the case where coordination network is formed only for shallow networking, high incentives motivating participating member or specific networking target goals is required beforehand for effective network maintenance.

B. Eigenvalue centrality: hierarchial network for effective networks

The hegemon within networks is not necessarily defective for collaboration. As a matter of fact, the result showed that despite of the potential for predominance, the hierarchical network structure is favorable to maintain shallow coordination and conduct effective engagement and proactive outputs within coordination networks. (Table 4) **[1]**

C. Implications on global C2C networks: Geographic extent and mitigation contribution

Although the international cooperation and coordination might not effectively contribute in bringing direct mitigation effects, its network somehow demonstrates the willingness and status degree of each participant country of the C2C network. In addition, the eigenvector centrality value describes the influence of each node (country) over other nodes, implying as well their exposure to information, knowledge and research opportunity of each participant country. The C2C network visualization clearly shows the geographical network extent (Appendix) including participant countries of each transnational C2C climate network from each continent.

VI. CONCLUSION

Network elements are identified as essential to bring proactive and effective engagement of city networks from the participant countries **[2] [4]**. In terms of city network centrality assessment, nodes and links are basic units for analysis **[13]**. The network centrality concept, which is used in various arenas including transportation, social networks, spatial analysis, etc. **[14]**, is used for this study to assess mitigation collaboration networks, including its characteristics, through the comparison to their active status.

The research suggests that connectivity degree does not seem to greatly influence over the effectiveness of the network structure. However, with the presence of a specific network element, and a hierarchical network, the network is favorable to maintain an effective and proactive status, which could to be considered in designing future C2C collaborations and networks.

In sum, although climate coordination and cooperation might only act as a catalyst for real mitigation impacts, the study aimed to find the influence of network elements and centrality characteristics over the active status degree of transnational C2C climate network. The network is expected to bring indirectly impacts through activities including knowledge exchange and collaborative research, engendering indirect mitigation impacts.

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APPENDIX

Fig. 1. C2C1- Visualization of IUC network connectivity (weighted links)

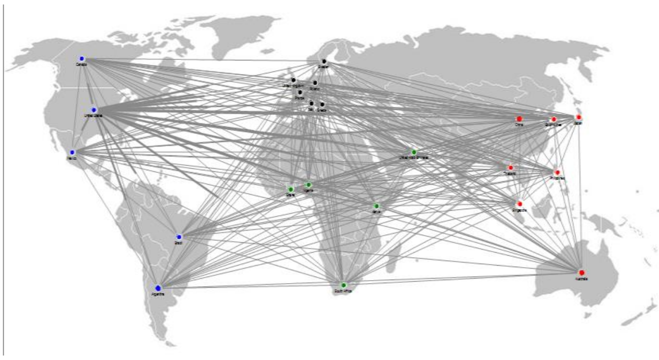

Fig. 2. C2C2- Visualization of C40 network connectivity (weighted links)

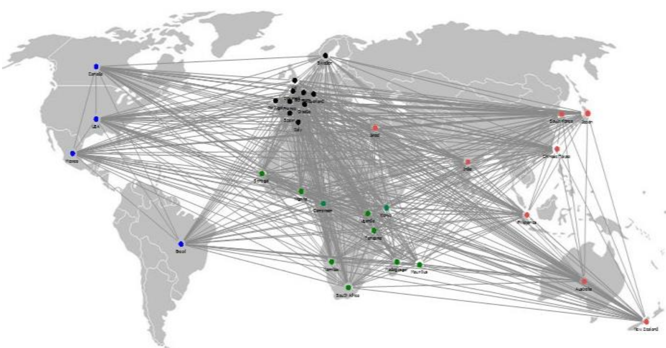

Fig. 3. C2C3- Visualization of the World Mayor's Council on Climate Change network connectivity (weighted links)

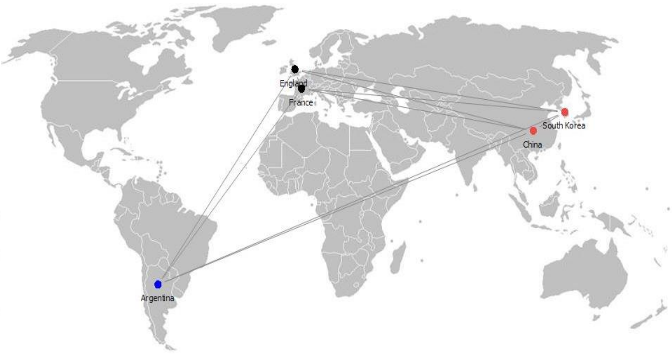

Fig. 4. C2C4- Visualization of the ISCI network (weighted links)