TIP Working Party
CO-CREATION PROJECT
2019-2020

Case study from Korea

Fighting fine dust - co-creation to improve air quality

OECD

Please cite as:

Sohn, Soo J.; Mok, Eunji; Choi, Chi-ho; Park, Jongbok; Park, Byeong Won; Choi, Yong In (2020), "Case study from Korea on fighting fine dust – co-creation to improve air quality. Contribution to the OECD TIP Co-creation project." Accessible online [as of 9/12/2020]: https://stip.oecd.org/stip/knowledge-transfer/case-studies

EXECUTIVE SUMMARY

For the past several years, South Korea has wrestled with the issue of fine dust that now poses a grave threat to people's daily lives and health. As result, the public is now paying serious attention to the quality of the atmospheric environment. In their attempt to join forces to reduce fine dust and improve atmospheric environment, some civil organizations and NGOs have proposed that the government take diversified approaches to analyzing the causes of fine dust and developing fine dust reduction measures.

In recognition of the need to develop science and technology-based countermeasures to tackle fine dust, the South Korean government has launched a pan-ministerial joint initiative. The Center for Particulate Air Pollution and Health ("PM Center" hereinafter), a pan-ministerial project group, is now functioning as an implementation platform for the initiative.

The South Korean government also enacted the Special Act on Fine Dust Reduction and Management in August 2018 and the Master Plan for Fine Dust Management in October 2019 to facilitate not only R&D, but also active communication among key stakeholders, including the general public, in the country's efforts to come up with effective and long-lasting solutions at the pan-ministerial level.

The PM Center was launched to conduct co-creation projects from the perspective of pursuing Research & Innovation. It can be interpreted as Research & Solution Development (R&SD) to formulate package solutions against this grave threat. The Center's key objectives are to develop technologies that can offer fundamental solutions to fine dust issues, to develop fine dust emission and exposure reduction technologies, and to propose feasible action plans for developing these technologies. The Center has established two channels of co-creation, namely R&D-led co-creation and policy-led co-creation.

First, for co-creation in R&D, the PM Center has paid attention to the fact that nitrogen oxides, one of the key contributors of fine dust, are inevitably generated in the process of fuel combustion and are key sources of air pollution. The Center also came to realize that package solutions can be developed using relevant source technologies currently possessed by the Korea Institute of Science and Technology (KIST), as the disposal of nitrogen oxides necessitates a denitrification catalyst. A consultation body has been formed as a partnership of multiple players for co-creation involving key stakeholders including KIST, government-funded research institutes (GRIs), universities, government, companies, and civil groups. Experts in this consultation body have supplied scientific data through the fine dust forecasting system by analyzing the generation and inflow of fine dust particles and developing a Korean-style air quality modeling system. GRIs and universities have played a leading role in this process, securing optimal package technologies through the so-called on-site test-bed process of dust collection and reduction technologies. This process requires sites adopting new dust reduction technologies to obtain new technology certification by providing test-bed results of their new technologies. Key roles have been played by GRIs, universities, and SMEs in this co-creation process.

As for co-creation in policy, the PM Center has also established a platform for communicating policies with key stakeholders to secure fine dust reduction solutions and their applicability and sustainability. The role of this communication platform is to help facilitate active communication among citizens and other key stakeholders from local governments, public agencies, universities, GRIs, and businesses so that they can jointly identify issues, present suggestions for improvement of the relevant laws and regulations, and propose policies and projects.

1. GENERAL CHARACTERISTICS OF THE CO-CREATION INITIATIVE			
Name of the initiative*:	**Co-creation for fine dust solution: Improving atmospheric environment using denitrification catalyst technology**		
Start date*:	**Since 2014**	Expected end date*:	**Undefined**
Country*:	**South Korea**	☐ International project *	
In the case of international projects, please specify the partner countries:			
Project budget*:	**About 43 $ million**	☐ Public funding *	
Main focus*:	☐ Research	☐ Economic	☑ Social

GOAL AND OBJECTIVE OF THE CO-CREATION INITIATIVE

Q1*. What is the **vision** of the co-creation initiative? (e.g., stimulating research and discourse about a new model of global governance; platform for outcomes-based innovation to save and improve lives in low-income countries)

Enhancement of people's quality of life by reducing fine dust through catalytic technology.

Q1A. What is the rationale behind the vision of the co-creation initiative?

Civil society's concerns are increasing due to global fine dust pollution.

Q1B. Was it someone's initiative or did you set it with all partners?

All partners

Q1C. Has the vision of the initiative ever been revised? Why?

None

Q2*. What are the main objectives of the initiative?

Linking technology development with the fine dust policy to solve the fundamental problem of fine dust.

Are there plans to **commercialise** the co-created products and/or services? Please explain

☑ Yes ☐ No

Technology spin-off companies established and invested by KIST develop and implement plans for commercializing co-created products and making inroads into overseas markets. KIST provides technology support for corporate research teams run by POSCO, Doosan and venture start-ups, so that KIST-owned technologies can be applied to sintering furnaces and cement plants.

Q3. What are the main **motivations** of the different partners to collaborate in this initiative (e.g., need for finance, competences and skills, network & connections of partners, risk sharing)

A commercialization path is completed by combining specialized competencies (e.g. technology, manufacturing, planning and funding) of different partners. For example, research institutes provide their originative technologies and high caliber researchers while universities carry out fundamental research. Companies also take part in the collaborative efforts by providing funding and test-beds for developing pollutant-minimizing processes. Civic groups also paly their part by continuously monitoring air quality and making steady efforts for the legislative revision to stipulate air quality improvement in the law.

FUNCTIONAL ROLES OF CO-CREATION PARTNERS

Q4A*. Specify all **partners involved** in the co-creation process (specifying the number of partners per type)

Q4B*. Choose the co-creation process (e.g., project) initiator(s)

Q4C*. Specify where partners are located

Q4D*. Specify what are the main activities and responsibilities of partners

Please read the contents at the end

Please, tick all appropriate answers in the table below.

	A.	**B.**	**C.** Location		**D.** Main activities						
	Partners for co-creation	Project initiator(s)	National	Foreign	Priorities setting	Research	Designing products	Experimentation and development	Commercialization / Support (marketing, consultancy, etc.)	Product launch	Financial engagement (share of funding, %)
Firms: POSCO, DOOSAN engine, SMEs											
Service											
Manufacturing	**3**	**V**	**V**			**V**	**V**	**V**	**V**	**V**	**50**
Research organizations: KIST(Korea institute of Science and Technology), Kyungki Univ. etc.											
Public research institutes	**2**	**V**	**V**		**V**	**V**	**V**	**V**			
Universities	**1**	**V**	**V**			**V**	**V**				**-**
Civil society:											
Non-governmental organizations (NGOs)	V										
Personal engagement	**V**	**V**	**V**								**0**
Government:											**50**
Public authorities	**V**	**V**	**V**								
Government agencies	V										
Transnational organizations											

Notes:

Projects have two main sources. One is the project proposals submitted to the government by research teams and the other is project ideas discovered and identified by the on-site watchdogs. Good examples of these watchdogs are the environmental NGOs.

Q5*. Were there any conditions to participate the co-creation initiative? (e.g. amount of funding provided, data sharing conditions, type of expertise, etc.)

It is important to reach a consensus on the appropriateness of and necessity for the resources under possession (e.g. technology, facility, and funding).
The funding for technology development is provided by the National R&D Program while companies provide funding for catalyst testing. When it comes to data sharing, KIST and POSCO try to improve data quality through data sharing and feedback. POSCO takes part in on-site pilot testing and test-bed activities.

Q5A. If there were any **criteria** for selecting partners, please, name them

Patents, market experiences, willingness, Social contribution

For each type of co-creation partner, please, provide the following information:

Q6*. Name of organization and website (if available)
We have the Center for Particulate Air Pollution and Health, or the PM Center in short, and the center uploads information on its activities and various events at its website (http://pmcenter.kist.re.kr/main/).

Q7*. Please explain the rationale of involving this partner in the co-creation project

Please read the contents at the end

Q8*. Explain, please, the role and main responsibilities of this partner in the co-creation project

Please read the contents at the end

Q9*. What is the financial engagement of this partner in the co-creation initiative (i.e. what is the share of funding they provide for each of the activities of the co-creation project)?

Industries (e.g. POSCO and Doosan) and the government respectively provide half of the funding.
Funding from the government is used for the lab testing and pilot testing of originative technologies while funding from industries cover test-bed and scale-up activities.

2. MANAGEMENT STRATEGY

Q10*. Who is responsible for co-creation **process management**?

Center for Particulate Air Pollution and Health

Was a steering group or advisory committee set up? If so, please provide details on its role and frequency of interactions.

[V] Yes [ ] No

A consulting group is being operated by the steering committee of the PM Center, an integrated platform for find dust reduction efforts. This advisory group monitors projects by quarter

Q11*. What is the **frequency of interaction** between co-creation partners?

☐ If necessary ☐ Once every few months ☑ Several times a month ☑ Regularly

Q11A*. Please describe the nature and frequency of interaction between all couples of partners

A bi-annual reporting is made to the PM Center once in every six months and an annual report is made to the entire public once in a year. Presentations are held periodically among project partners. Whenever issues arise, project partners take part in the discussions of the related issues on an on-going basis.

Q12*. What are the **main means of communication** among co-creation partners? *(Please choose all appropriate answers)*

a) (V) Official meetings at the end of the reporting period (quarterly, yearly)
b) (V) Sharing of newsletters, documents, reports, publications
c) (V) Digital tools (e.g., email communication, conference calls, internet platforms)
d) (V) Conferences, workshops, etc. engaging external stakeholders
e) (V) Personal meetings
f) Other ____________________________

Q13. Is there an partnership **agreement** for the co-creation initiative ?

☑ Yes ☐ No *(go on to question Q13C)*

Q13A. Is the agreement formalised? ☑ Yes ☐ No

Q13B. Specify, please, the type of the agreement:

a) (V) Legal agreement
b) Memorandum of understanding
c) Other ____________________________

Q13C. Are legal issues related to the ownership of jointly developed IPRs settled in a partnership agreement?

☑ Yes ☐ No

Q13D. In case there is *no agreement*, please explain how partners' activities are coordinated

Q14A*. Who is the **owner of data** from the co-creation initiative?

Sharing all Partners

Q14B*. Who is the **owner of IP** from the co-creation initiative?

The owner of IP is determined either solely or jointly by its contributor(s). In case of joint development, IP is jointly owned. The license can be used by any South Korean company who needs it.

Q15*. How is the process of **accessing research results** (for partners) organized?

When R&D outcomes are created, project partners are notified of it and a procedure to protect their rights immediately follows.

Access to the R&D outcomes is allowed in accordance with the basic IP principles. Participating companies in the project can claim their rights to the priority license.

Data is shared in real time, so the results of the on-site pilot testing are transmitted and confirmed in real time.

Results of the pilot testing including research notes or prototypes are verified by KIST and are immediately shared among partners.

Q16*. How do you set the **balance between data sharing and IP protection?**

There is a general agreement in the form of a standard R&D contract among participating partners. In addition, there exist individual agreements (e.g. licensing contracts such as priority license) signed by related partners when it comes to specific research data and IPs.

Q17. Is **public access** to either co-creation results or products granted?

R&D information can be accessed from the "National Technology Bank(NTB)", which manages national technology assets collectively. And through the "NTIS(National Science & Technology Information Service) website", we share information related to national R&D project and science and technology information.

Q18*. What types of **intellectual property (IP) protection mechanisms** are used (e.g., patents, trademarks, industry design, utility model, complexity)?

Patents

Q18A*. What types of IP are more important for your co-creation processes?

Patents

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3. PROJECT EVALUATION

Q19*. Are **milestones and key performance indicators (KPIs)** set for the co-creation initiative?

[V] Yes [ ] No

If *YES*,

Q19A. Are they settled in a partnership agreement?

[V] Yes [ ] No

Q19B. Are they essentially qualitative or quantitative?

[V] Qualitative [ ] Quantitative [ ] Both

Q19C. Please provide the main KPIs (provide up to 5 indicators)

There are three key KPIs or objectives.

1) Improve the efficiency of removing existing NOX by 30%,
2) Lower the catalyst activation temperature down to 220 degrees Celsius (low-temperature catalyst), and
3) Regenerate catalyst at 280 degrees Celsius.

Q20*. At what stages is the **evaluation** implemented? *(Please choose all appropriate answers)*:

[V] Ex-ante [V] Interim [V] Ex-post [ ] No evaluation procedure

<u>For each evaluation stage</u>, please, provide the following information:

Q20A. What approaches are used?

It is determined whether to continue to support the project depending on the results of the annual evaluation. To differentiate the project from other existing ones, real-time review and monitoring is conducted through an on-going evaluation system and follow-up activities are carried out immediately after the evaluation.

Q20B. What types of data are used?

The project outcomes are analyzed from four criteria; appropriateness, effectiveness, efficiency, and sustainability.

Q20C. How is the evaluation process organised? Who is responsible for it? Are there any external evaluations conducted?

Q21. Are the evaluation results open (e.g. published on the website, reports, structured databases, etc.) or closed (used only for the internal goals)?

☐ Open Please, specify: ______________ ☑ Closed

Q22. What are the **implications of** any **evaluations** conducted so far (e.g., revision of KPIs; suspension or termination of funding; penalties and rewards associated to performance)? Please explain.

awards associated to performance(ex. a Presidential citation)

Q23. What are the **key success factors** of this co-creation initiative?

Please read the contents at the end

Q24. Were there any **challenges** during the co-creation process? Please provide details and explain what caused them.

Please read the contents at the end

Q25. Based on your experience, what would you recommend to a new co-creation initiative for it to be successful? Please explain the main **lessons learned** from your experience.

Please read the contents at the end

4. THEMATIC FOCUS

Please select one of the two themes below and answer the corresponding questions:

Theme 1. Co-creation's contributions to digital innovation and AI and effects of data sharing

Theme 2. Effective involvement of NGOs and civil society at addressing societal challenges

- Please read the contents at the end

5. POLICY CONTEXT

Q26. Was the initiative supported by a specific policy initiative? If so, please provide details on the policy initiative and type of support provided (e.g. amount of funding, conditions of support, selection criteria, reporting obligations, etc.).

The initiative was conducted in accordance with the pan-ministerial plan on fine dust reduction. Multiple ministries can jointly plan projects through the PM Center, but they have no reporting obligations.

Q27. What are the factors (e.g. related to regulations, policy, business environment etc.) supporting and/or hindering co-creation in your country? Please explain.

Please read the contents at the end

Q28. What do you think are most effective types of policy support for co-creation?

Long-term R&D Support Policy

-------- CASE STUDY AUTHORS --------

Name: STEPI co-creation research team(Soo J. Sohn, Eunji Mok, Byong-won Park, Yong-in Choi), Chi-ho Choi(KIST), Jong Bok Park(Gyeongnam National University of S&T)

Location (country): South Korea

Affiliation: STEPI

Your role in the co-creation process:

Your main activities in the co-creation process:

Co-creation for find dust solution in South Korea

Introduction

A historical review of the key themes in South Korea's knowledge dissemination and technology commercialization reveals that the country's efforts in the 2000s were focused on enhancing the capacities of technology agents such as research institutes, industries, and their affiliated technology transfer organizations. This approach was taken based on an assumption that a transfer of leading technologies developed by public research institutes (PRIs) using such enhanced capacities would enable industries to efficiently translate technologies into products that are readily applicable to industry users. Later in the 2010s, such concepts as technology value-up or scale-up started to be highlighted in recognition of the importance of the technological linkage between technology agents and buildup of their technological capacity. This has led to the country's emphasis on TRL (Technology Readiness Level) and MRL (Manufacture-Readiness Level). This approach calls for sustained growth to keep pace with advances in technology and manufacturing. The so-called "co-creation" approach explained in this case study emphasizes the need for "working together" among all stakeholders to achieve the above-mentioned sustained growth and seamless value creation. This co-creation approach asserts that all the stakeholders should be involved in discussing and defining their roles and they should closely collaborate with each other in fulfilling those roles instead of assigning roles exclusively to certain agents in each step towards the goal of sustained growth and seamless value creation. It also calls for adjusting roles and responsibilities of all involved stakeholders through an exchange of feedback on the limitations they face in the process of fulfilling their responsibilities. In this approach, the task of designing research questions goes beyond an academic pursuit. It incorporates various kinds of needs such as industrial, market and public needs. In addition, the testing of prototype products is not left to industries alone. It is done through collaboration between researchers and users by applying the prototype products to actual use and modifying and improving them accordingly.

In the uni-directional approach to technology creation and use, as described in Table 1, technology and market uncertainties arising in the transition of technological knowledge or the research outcomes into technology products make it extremely difficult to translate technologies into products.

Table 1. Unidirectional Structure of Technology Creation and Utilization

(Player)	(Research)		(Industry)		(Entrepreneur)
Main Focus (Outcome)	R&D (Technological Knowledge)	⇨	Products (Products using the Technology)	⇨	Markets (Enterprises using the Technology)

Activities	Setting a Research Question Conducting a Research Securing Knowledge(Technology)	Designing Products based on Knowledge(Technology)	Designing the Markets based on Products

To overcome difficulties of translating technological knowledge into products and further into corporate growth, and to achieve innovative growth in an efficient manner, a collaborative approach is suggested in Table 2. This approach enables research planning and technological knowledge creation based on stakeholders' common needs, and it also makes collaborative testing possible. This will then allow products to be tailored to market demands so they can successfully enter the targeted markets and attain the desired growth. Therefore, research planning, knowledge creation, testing, product manufacturing, and market entry by a single player is no longer a powerful option. Now is the time for various innovation agents to collaborate in creating technologies, products, and markets by mobilizing their expertise, resources, and capacities. Such a collaborative approach will expedite market entry while minimizing technological uncertainty. This implies that innovation is now possible only through an orchestration of innovation activities.

Table 2. Co-creation of Technology and Utilizing Structure

(Player)	(PRIs, Industry, Civil Society, Government)		(PRIs, Industry, Civil Society, Government)		(PRIs, Industry, Civil Society)
Main focus	R&D (Technological Knowledge)	⇨	Product development (Products using the Technology)	⇨	Markets (Enterprises using the Technology)
Activities	**Sharing Research needs** Setting a Research Question Conducting Research Securing Solution		Designing Products based on the Research Solution **Verification of Demand Conformity**		Designing the Markets based on Products

1. Background

For the past several years, South Korea has wrestled with that fine dust[i] issue that is now posing a grave threat to people's daily lives and health. As result, the public is now paying serious attention to the quality of the atmospheric environment. While the primary sources of fine dust emissions are known to be chimneys of industrial sites and vehicles, a significant amount of fine dust is also produced through secondary chemical reactions of substances floating in the air such as sulfur oxide (SO_x), nitric oxide (NO_x), ammonia (NH_3), and volatile organic compounds (VOC). A Korea-US joint study on the air quality in 2016 revealed that more than 75% of fine dust emissions come from secondary chemical reactions.

In its report on «The Economic Consequence of Outdoor Air Pollution» in 2016, OECD projected that air pollution-related healthcare costs to be caused by air pollutants like ultra-fine dust would increase from USD 60 billion in 2015 to USD 280 billion in 2060, reflecting decrease in GDP and increase in both illness and mortality. The report also estimated that the market costs of air pollution flowing from additional health expenditures reduced labor productivity and crop yield losses, leading to global annual economic costs of 0.63% of global GDP. Other studies also forecast a significant negative impact of fine dust on health and production activities, suggesting immense economic losses.

The annual average concentration level of ultra-fine dust in South Korea has continued to improve gradually, but is still far from meeting the environmental standards. South Korea's fine dust level is reported to be largely affected by emission sources like industrial sites, power plants, and transportation volumes. The county's regional fine dust concentration level turns out to be closely related to the regional concentration of these emission sources. In some regions, fine dust concentration level has exceeded environmental standards by more than 60%; for example, Chungbuk, Jeonnam, and Gyeongbuk Provinces, where industrial complexes and power plants are concentrated, and some parts of Gyeonggi Province with heavy traffic.

In South Korea, the duration of fine dust concentration shows seasonal variation. In 2018, the average number of days with a «bad» fine dust level was 59 days. The country's fine dust concentration turned out to be especially high in winter and early spring seasons December through March, when the days with «bad» find dust levels mostly occurred. During this period, when the wind is blowing from the northwest and west, the country's air quality is reported to be affected more by external factors than domestic emission sources. An increase in the number of days with bad fine dust levels has now become an issue threatening the quality of life, as polluted air constrains people's activities and lifestyles, negatively affects their health, and causes economic losses.

In their attempt to join forces to reduce fine dust and improve the atmospheric environment, some civil organizations and NGOs have proposed that the government take diversified approaches to analyzing the causes of fine dust and developing fine dust reduction measures.

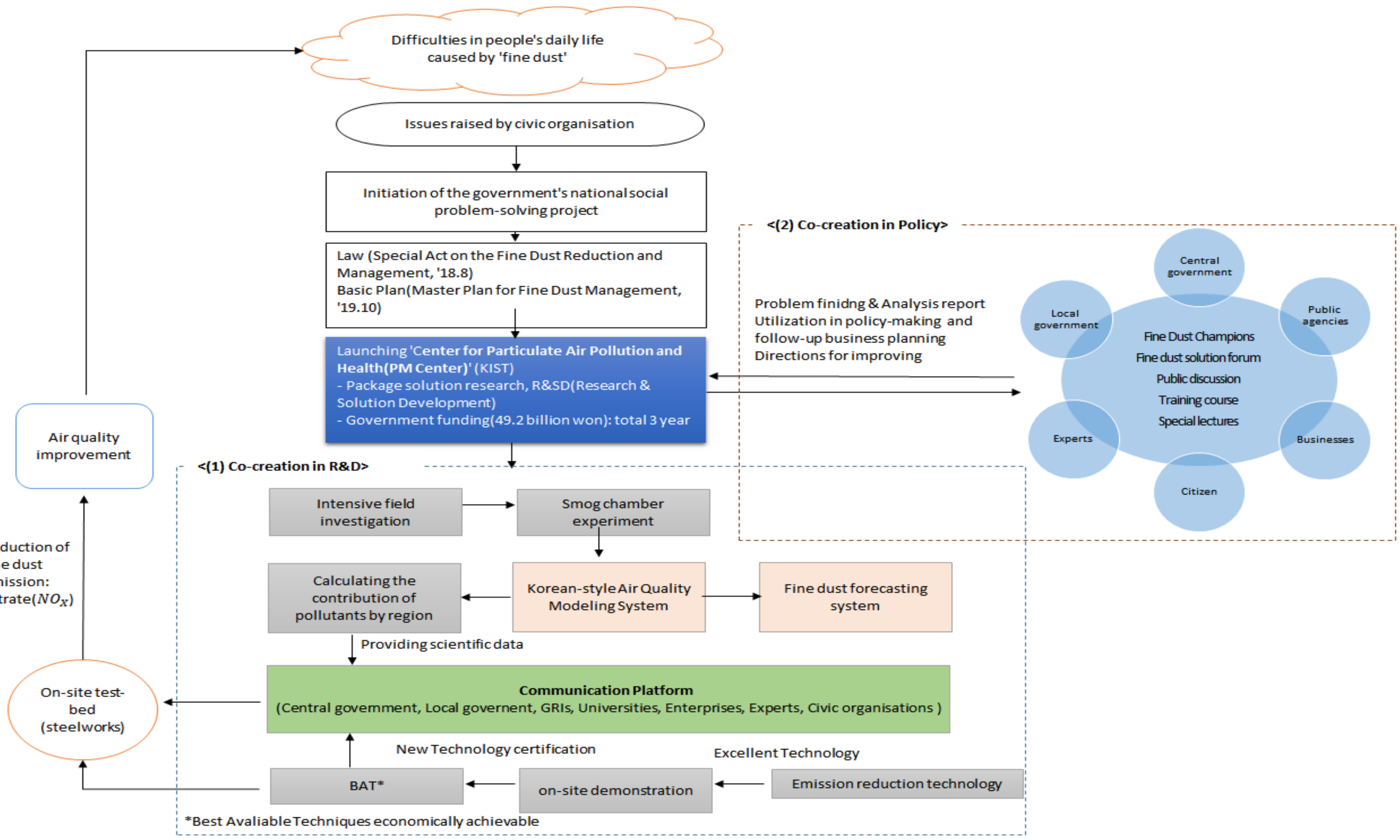
2. Building governance for carrying out projects to solve the nation's social issues

The South Korean government enacted the Special Act on the Fine Dust Reduction and Management in August 2018 to facilitate not only R&D, but also active communication among key stakeholders, including the general public, in the country's efforts to come up with effective and long-lasting solutions at the pan-ministerial level.

A pan-ministerial body called the Special Committee for Fine Dust Reduction has been formed to combat fine dust issues. This committee is co-chaired by the prime minister and the president of the University of Science and Technology (UST), and it consists of 40 members, including private sector experts and ministers from relevant ministries such as the Ministry of Science, ICT, the Ministry of Environment, the Ministry of Land, Infrastructure, and Transport, and the Ministry of Trade, Industry, and Energy. The committee deliberates and decides on key fine dust-related policies. Additionally, the South Korean government announced the Master Plan for Fine Dust Management in October 2019. This is a five-year basic plan presenting the country's key policy directions and initiatives for curbing and managing fine dust particles. The plan is legally binding and has strong administrative power, as it was mapped out based on Article 7 of the Development of a Mast Plan for Fine Dust Management of the Special Act on the Fine Dust Reduction and Management. The plan sets out a fine dust management target of reducing the country's annual ultra-fine dust concentration by 35% from the 2016 level, and it presents management guidelines accordingly. The plan will be implemented over a five-year period from 2020 to 2025. Initially, a draft plan was jointly developed by relevant ministries, and feedback on the draft plan was gathered from local governments and experts. Then, the plan was reviewed and finalized by the Special Committee for Fine Dust Reduction. As an overarching plan on the fine dust issue, this master plan has also incorporated progress from other previous plans such as the Comprehensive Plan on Fine Dust Management in 2017 and the Policy Measures for Strengthening Fine Dust Management in 2018. The key initiatives included in the master plan have been designed in consideration of other initiatives for reducing local fine dust emissions. These initiatives are intended to promote international cooperation, infrastructure building, and communication in the country's fine dust reduction efforts. The country's efforts to reduce fine dust concentration are especially well reflected in international cooperation initiatives such as a South Korea-China joint initiative for Clean Sky Project, a project for building a forecast sharing system. The plan also includes measures to promote cooperation with international organizations in coping with air pollution through an international initiative called the North East Asia Clean Air Partnership (NEACAP). Base on the master plan, a standard manual for disaster and crisis management has been drawn up within the framework of protecting public health. The manual requires upgrading a control tower's power by concentration level and employing stricter measures when necessary, depending on the fine dust situation. Especially during the high concentration season from December through March, the manual requires the implementation of additional fine dust reduction measures. In accordance with the master plan, the Master Plan for Air Quality Control and action plans for respective regions have been mapped out. Within these legal and administrative frameworks in recognition of the need to develop science and technology-based countermeasures to tackle fine dust, the South Korean government launched a pan-ministerial joint initiative on fine dust. The Center for Particulate Air Pollution and Health (PM Center hereinafter) as an implementation platform of the initiative was launched to conduct co-creation projects from the perspective of pursuing R&SD package solutions.

The Center's key objectives are to develop technologies that can offer fundamental solutions to fine dust issues, to develop fine dust emission and exposure reduction technologies, and to propose feasible action plans for developing these technologies. A total budget of 49.2 billion KRW (or about 40 million USD) has been allocated for carrying out projects over three years (May 2017~May 2020). The South Korean government has supported fine dust reduction efforts of other stakeholders like research institutes, industries, and civil groups by developing pan-ministerial Comprehensive Measures for Fine Dust Management, launching the Coordinative Committee for Fine Dust R&D, and mapping out a Find Dust Technology Development Roadmap. The Climate and Environment Response Team of the Ministry of Science and ICT injected KRW 14 billion in 2019 in R&D funds to support the development of fine dust reduction technologies.

Fig. 1 Overview of co-creation for fine dust solution in South Korea



(1) Fostering R&D basis: Co-creation in R&D

For the purpose of minimizing research gaps and strengthening research collaborations, research projects have been categorized based on their key features. For upgrading monitoring and forecasting capacity, weekly fine dust forecasting is being implemented by launching a multipurpose stationary satellite and expanding monitoring networks to cover ships, islands, and border areas. This has increased fine dust monitoring frequency from once a week to once a day, and this daily monitoring will be expanded gradually to 19 regions throughout the country. For an accurate measurement of fine dust emissions, undetected emission sources have been discovered, and emission volumes have been adjusted at the national level by using monitoring data from environmental satellites. In addition, the K-MEMS system, a Korean-type air quality forecasting system, has been developed.

As result, diverse players with research capacities are now concentrated on an R&D platform for resolving fine dust problem under the lead of GRIs, having their own roles and responsibilities as shown in Table 3.

Table 3. Role & Responsibility of the players in R&D co-creation

Player	Role & Responsibility
Government	R&D investment, policy environment control, regulation improvement, establishment of dedicated organization(control tower)
KIST(GRI)	Technology creation, demonstration, application design
University	Basic research, proof of concept
Enterprise(Industry)	Demonstration, commercialization
Civiil Society	Problem definition, issue & idea raising

(2) Strengthening policy basis: Co-creation in policy

The PM center not only supports research, but also operates communication channels for policy. The channels can be approached from a policy co-creation perspective. They try to build an environment for raising public awareness and understanding of players. Public awareness and understanding of fine dust-related policies and public responsibilities have been enhanced through educational programs, forums, and public discussions. Their overall roles are specified in Table 4.

Table 4. Role & Responsibility of the players in policy co-creation

Player	Role & Responsibility
Government	Monitoring policy needs, providing communication channels, policy promotion
KIST(GRI)	Planning post-R&D, communication with research groups

Civiil Society	Monitoring, policy suggestions, policy participation(committee)
University	Education and training courses
Entreprise	Business planning, start-up/spin-off launching
Public agency	Problem monitoring, analysis reporting, network operating
Experts	Special lectures for the public

3. Co-creation led by the PM Center

(1) Co-creation in R&D

The PM Center paid attention to the fact that nitrogen oxides, one of the key contributors of fine dust, are inevitably generated in the process of fuel combustion and are key sources of air pollution. The Center also came to realize that package solutions can be developed using relevant source technologies currently possessed by the Korea Institute of Science and Technology (KIST), as the disposal of nitrogen oxides necessitates denitrification catalysts.

The environment-friendly denitrification catalyst technology developed by KIST is cheaper than other existing catalyst technologies by more than 30%. Its durability is also excellent, as it shows high catalytic activity at low temperatures. These superior features increase the possibility for this technology to be translated into products that can lead the global market. KIST's catalyst technology also has high applicability, as it can be used as an effective tool for meeting ever-intensifying regulations on greenhouse gas emissions. It can be rated as world-class technology, as it does not require any extra special devices but is still capable of eliminating up to 90% of nitric oxides in low temperatures around 220 degrees Celsius. A common understanding has been reached that this technology has high potential as an effective tool for mitigating fine dust particles and thus meeting fine dust reduction needs. Based on this understanding, a consulting body has been formed as a partnership of multiple players for co-creation involving key stakeholders including KIST, universities, government, companies, and civil society.

Experts with this consulting body have supplied scientific data through the fine dust forecasting system by analyzing the generation and inflow of fine dust particles and developing a Korean-style air quality modeling system. GRIs and universities have played a leading role in this process. They have succeeded in securing optimal package technologies through the so-called on-site test-bed process of dust collection and reduction technologies. This process requires sites adopting new dust reduction technologies to obtain new technology certification by providing test-bed results of their new technologies. Key roles have been played by GRIs, universities, and SMEs in this co-creation process.

As Table 5 shows, relevant projects have been organized by phase.

Table 5. Contents of projects

phase	projects
Generation·Inflow	Identification of the mechanism of generating fine dust in Northeast Asia using a smog chamber
	Establishment of aerial measurement system for three-dimensional monitoring of fine dust
	Identification of causes and quantitative contribution of fine dust to respond to current issues
	International Joint Observational Study for Identification of Fine Dust Movement in Northeast Asia
Measurement·Forecast	Development of Korean integrated air quality measurement and forecast system
	Development of movable low-altitude fine dust observation system
Dust collection·Reduction	Real-time demonstration of low-cost, high-performance Long Bag Filter
	Development and demonstration of technologies related to dry desulfurization and low temperature SCR denitrification catalyst for steel mill sintering furnace
	SOx, NOx particle conversion in SME sites and development of high-viscosity particulate matter filtration dust collection system
	Development of selective SO2 separation process technology to decrease fine dust
Protection·Response	Development of integrated management technology and real environment evaluation standards for real housing environment
	Development of filter materials and life protection products to decrease fine dust
	Evaluation of human health impact on fine dust
	Research on air pollution health effects such as fine dust in Korea and set up a health impact map
	Research on prevention and management of fine dust and yellow sand health damage and effectiveness of health masks

Research institutes and industries have held different perspectives on R&D implementation. In fact, such differences have worked as complementary elements in conducting R&D, which has led to the expedited process of producing R&D outcomes. For example, industrial sites like steelworks shared issues they faced in the process of actually using technologies with research institutes. In analyzing data for catalyst testing, for instance, skilled technicians with accumulated field experience in industrial sites held different views from those of researchers. While researchers had a rather microscopic perspective, industries took more macroscopic approaches. So, the two parties had to compromise their approaches to minimize their differences. In the meantime, universities conducted strategic originative researches to delve into phenomena all stakeholders face in the process of implementing R&D. KIST and the Center for Particulate Air Pollution and Health (PM Center) jointly tested the effectiveness of catalysts in treating precursors like nitric oxide, sulfur oxide, ammonia, and VOC. Among the primary sources of nitric oxides are power plants, steelworks, furnaces, and cement factories. For power plants, however, catalyst technology is no longer a highly advanced technology, and they have already previously used various catalyst technologies. In the meantime, it has been proven that it is far more difficult to apply catalyst technologies to sintering furnaces at steelworks than other sites, so technological expandability can be enhanced if the durability of catalyst technologies can be maintained at a low temperature.

Scientific data and package technologies that have been secured from this process have been actually applied to such sites as steelworks. As result, it is now possible to estimate the positive impact of reduced nitric oxide (NOx).

Civil society also offered a new perspective on the direction of R&D that researchers and industries were seeking. For example, citizens' call for reducing fine dust mainly targets spaces that are closely related to their daily lives, including indoor spaces, subways, and schools. So, the fine dust reduction model for these places has also been incorporated into the R&D planning process.

(2) Co-creation in Policy

The PM Center has also established a platform for communicating policies with key stakeholders to secure fine dust reduction solutions and their applicability and sustainability. The role of this communication platform is to help facilitate active communication among citizens and other key stakeholders from local governments, public agencies, universities, GRIs, and businesses so that they can jointly identify issues, present improvement suggestions in relevant laws and regulations, and propose policies and projects.

Furthermore, the Center encourages active participation of key stakeholders and the general public in the communication process by hosting a Fine Dust Champions' Training Course, Fine Dust Solution Forum, Public Discussion, and special lectures, opening research sites, and publishing newsletters. These opportunities give key stakeholders and citizens easy access to information on the relevant issues. They also allow the general public to comply with policies concerned. In particular, the Fine Dust Champions' Training Course is an educational program hosted by the PM Center and organized by local governments and environmental NGOs for the purpose of enhancing the public's understanding of fine dust and their ability to reduce fine dust exposure in daily life. Through this program, citizens can enhance their knowledge of fine dust and the center can share fine dust-related information with citizens and extend its efforts to apply technologies to citizens' livelihoods while constantly monitoring their basic needs. In the meantime, the Fine Dust Solution Forum sets fine dust-related topics such as fine dust diagnosis and its solutions, forecasting and countermeasures, outdoor and indoor air quality, standards and their management, childcare and environment, ozone and fine dust, and energy and air pollution. The forum hosts presentations by experts on each topic, discussions between the public and experts, communication with the public, and educational sessions on the proper use of face masks. As part of the forum, issue reports on major countries' fine dust management approaches are published. All these activities lead to new fine dust-related research projects. In short, this allows a virtuous cycle of incorporating the public needs into R&D planning through education and communication.

4. Impact

Technologies accumulated in the above-mentioned R&D have been translated into patents in improved forms and are now being used to treat nitric oxides emitted from petrochemical plants in South Korea. This achievement is expected to facilitate technology dissemination into major Asian countries, the key emitters of nitric oxides, and help their efforts to reduce fine dust particles. It has been also confirmed that technology development and testing can also foster the startup of technology ventures. For this purpose, government is now setting up technology investment companies and planning various types of market entry models. When it comes to market entry models, two models are mainly considered, one through technology transfer and the other through joint ventures.

In case of matured technologies, technologies have been transferred to existing participants, and markets are being developed mainly by technology investment companies or technology incubators. On the other hand, for future-oriented technologies, markets are being developed through global joint ventures like global catalyst companies.

As an outcome of this project, PRIs will be able to attain strategic originative technologies and enhance their patent competitiveness in the global market. SMEs will be able to secure business seeds like catalyst modules while large corporations can pursue maximum profits through cost savings. In particular, civil society will be able to enjoy outdoor activities in a less polluted environment with reduced fine dust particles, which will then improve people's life satisfaction and wellbeing.

5. Implications

Speedy action is often said to be more important than R&D to resolve environmental issues like fine dust. This implies that technology commercialization requires a timely and speedy use of appropriate technologies. A single stakeholder alone cannot move this fast-paced process forward. It requires a collaborative model that can minimize unnecessary conflicts between various stakeholders. The co-creation model makes all this possible. For example, industries are often required to provide test-bed sites. When unnecessary conflicts arise in the process of providing test-bed sites, it can halt the entire process. When this happens, the government needs to provide necessary support to resolve such conflicts and thus ensure a proper functioning of this co-creation model by easing regulations. Co-creation can succeed only when all stakeholders work closely together for their mutual benefit in a collaborative manner.

In fact, building credible relations between stakeholders is as important as enhancing technological capability when creating economic and social value through co-creation. A model can be successfully designed and implemented in a manner that ensures win-win solutions for all involved stakeholders only when a consensus on the shared goals of co-creation has been reached and incentives for participation have been clearly defined and provided.

[ii] PM 10 fine dust refers to dust particles with a diameter not exceeding 10 micrometers, while PM 2.5 ultra-fine dust refers to smaller dust particles with a diameter not exceeding 2.5 micrometers.