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지질자원기술분야 연구개발활동 온실가스 배출량 산정 사례연구 – 한국지질자원연구원 기본사업을 대상으로 –

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A Case Study on the Calculation of Greenhouse Gas Emissions in Research and Development Activities of Geo-Technology in Korea: A Study on the Basic Projects of the Korea Institute of Geoscience and Mineral Resources

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요 약: 한국지질자원연구원은 기관차원의 연구활동에 따른 온실가스 감축 기여를 활성화하고자, 온실가스 배출량 산정 가이드라인을 개발하고 이를 적용하고자 하였다. 이에 시범적으로 2022년도에 현재 수행중인 기본사업 34건의 R&D 활동 그 자체에 의한 온실가스 배출량 규모를 파악하였다. 개별과제의 연구계획 내용과 예산내역을 분석하여 여러 온실가스 배출범위와 경계를 정하였으며, 직접배출원, 간접배출원, 기타 직·간접 배출원 등 22건을 도출하여 해당 연구활동에 의한 배출량을 시범 산정하였다. 그 결과, 한국지질자원연구원 2022년도 기본사업 R&D 활동에 의한 온실가스 배출량은 전체 2,041.506 tCO2eq으로 산정되었고, 그 중 직접 배출량은 793.235 tCO2eq (38.86%), 간접 배출량은 305.647 tCO2eq (14.97%), 기타 직·간접 배출량은 942.624 tCO2eq (46.18%) 이었다. 2022년도 한국지질자원연구원의 기본사업 투입예산(총액 966.61억원)에서 1억원당 온실가스 배출량은 2.11 tCO2eq으로 산정되었고, 참여연구원 1인당(참여율 100% 감안) 온실가스 배출량은 4.800 tCO2eq으로 추정되었다. 이러한 연구과제의 온실가스 배출량 산정연구는 1회성 보다는 지속적으로 매년 정기적으로 수행하고, 최소 5년 이상 정도의 축적이 이뤄져야만 연구분야 특성과 연구방법의 상이에 따른 배출량 증감 및 특이사항의 정형화가 가능할 것이며, 향후 배출량 관리방향 설정과 ESG경영의 환경부문 기여도 평가에도 활용이 가능할 것으로 사료된다.

핵심어: 온실가스 배출, R&D 활동, 배출원, ESG경영

Abstract: This study aimed to develop and apply guidelines for calculating greenhouse gas emissions to activate the contribution of the Korea Institute of Geoscience and Mineral Resources (KIGAM) for institutional-level research activities. In addition, we intended to improve awareness by identifying greenhouse gas emissions from KIGAM's basic research and development (R&D) activities in fiscal 2022. Herein, the research plan and budget contents of individual projects were analyzed, whilst the boundaries and scopes of greenhouse gas emissions were determined, with 22 cases being derived as either direct, indirect, or other sources of emissions. Subsequently, research activity emissions were calculated by emission source. The greenhouse gas emissions of KIGAM's 2022 basic project R&D activities were 2,041.506 tCO2eq, of which direct emissions were 793.235 tCO2eq (38.86%), indirect emissions comprised 305.647 tCO2eq (14.97%), whilst other emissions were 942.624 tCO2eq (46.18%). In particular, greenhouse gas emissions per 100 million won in the KIGAM's basic projects for fiscal 2022 (a total of 96.661 billion won) was calculated as 2.11 tCO2eq, whilst greenhouse gas emissions per participating researcher (was 4.800

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tCO2eq. Such calculations should be carried out annually rather than once and accumulated for at least 5 years. Accordingly, it will be possible to standardize specific matters that influence emissions according to differences in research field characteristics and methods, thus guiding greenhouse gas emission reduction management in the future and evaluating the contributions of Environmental, Social and Governance (ESG) management to the environmental sector.

Keywords: Greenhouse gas emissions, R&D activity, reduction, ESG management

INTRODUCTION

The Korea Institute of Geoscience and Mineral Resources (KIGAM) has been somewhat negligent in considering individual projects such as environmental destruction, social responsibility, and safe and transparent research activities (management). However, carbon-neutral contributions and Environmental, Social and Governance (ESG) evaluation results are reflected in the creditworthiness of companies and the soundness of public enterprises/public institutions in Korea. Public enterprises/institutions are also actively promoting related activities through the publication of sustainability reports. If the target amount of research and development results remains the same, research and development methods with relatively low carbon emissions should instead be prioritized. The unit used in this study, tCO2eq means a significant amount of carbon dioxide tons. It is a unit used to measure the amount of greenhouse gases released into the atmosphere. 1 tCO2eq is equivalent to 1 t of carbon dioxide or other greenhouse gases.

In KIGAM's research and development (R&D) activities in geo-technology, sustainability (ESG), environmental protection, social contribution, and ethics management (Governance) lacked sustainability as a superficial approach, but in 2014, it received excellent reports for supporting educational donations and the shared growth of small and medium-sized enterprises. However, the overall approach and governance of carbon emissions reduction and Net-Zero contribution activities in KIGAM R&D activities were insufficient. Therefore, there is a need for preliminary research to establish an inventory base to manage carbon emissions at an institutional level, which should include the Net-Zero contribution perspective and ESG aspects when establishing institutional development plans and mid- to long-term R&D plans.

TREND ANALYSIS OF TECHNOLOGY DEVELOPMENT

Korea's provisional greenhouse gas emissions in 2021 were estimated to be 679.6 million tCO2eq, using information such as energy statistics monthly report, import and export statistics, livestock trend surveys, and information on the emissions trading system. This figure was increase of 3.5% on the previous year, whilst being 6.5% lower than that in 2018, when peak emission levels were recorded. Korea's current emissions growth rate (3.5%) is lower than the global average (5.7%) and growth rate in major countries (6.2% in the U.S., 7% in the European Union, and 4.8% in China). Considering the proportion of emissions by sector in Korea, the energy sector accounted for 86.9%, with 590.6 million tCO2eq, followed by 7.5% from industrial processes (51.0 million tCO2eq), 3.1% from agriculture (21.2 million tCO2eq), and 2.5% from waste (16.8 million tCO2eq; GIR, 2021).

Until recently, Korea has actively carried out measures to calculate greenhouse gas emissions in each field, region, institution, and area. Additionally, the Korean government has established the Greenhouse Gas Information Center (www://gir.go.kr) of the Ministry of Environment to continuously build and spread greenhouse gas information. Furthermore, the Global Climate Change Intergovernmental Panel (IPCC) published the 2006 IPCC guidelines for creating a national greenhouse gas inventory. The Guidelines for the operation of greenhouse gas and energy target management, etc. (Ministry of Environment Notification No. 2016-255; Ministry of Environment, 2016), Guide-

lines for Greenhouse Gas/Energy Statement of Goal Management, Manual Part (Korea Environment Corporation, 2015a, 2015b, 2015c, 2015d), Guidelines for the operation of greenhouse gas and energy target management in the public sector (Ministry of Environment Notice No. 2012-22; Ministry of Environment, 2012), Guidelines for Establishing Voluntary Greenhouse Gas Inventory for Small and Medium Enterprises (Korea Environment Corporation, 2015e), Guidelines for Building Greenhouse Gas Inventory for Universities (Korea Environment Corporation, 2011), and Guidelines for Calculating Greenhouse Gas Emissions by Local Governments (Korea Environment Corporation, 2017) were all published in Korea.

Research into actual cases and methods for calculating greenhouse gas emissions in Korea is also being actively conducted. For example, Kwak *et al.* (2015a, 2015b) conducted a calculation of the basic unit of carbon emissions in the Operation and Maintenance Stage of Road Infrastructure, whilst Kim and Jang (2013) conducted a study comparing the CO_2 emissions estimated results for construction equipment, and Jang and Kim (2013) conducted a study on the application of CO_2 and hydrometer sensors for the development of a real-time measurement method for CO_2 emissions from construction equipment. Additionally, Kim *et al.* (2021) conducted a study on the estimation methods for life cycle GHG emissions for the mine reclamation project, Kim *et al.* (2014) published a study on the estimation of the energy consumption and CO_2 emission intensity during building construction, and Kim and Tae (2010) conducted a study on the development of an evaluation system for CO_2 emissions during the production of concrete. Furthermore, Seo *et al.* (2012) developed Smart Phone Applications for Individual carbon emissions saving measurements, whilst Oh *et al.* (2011) conducted a study for construction of a CO_2 inventory using GIS, and Jun *et al.* (2011) released a system for estimating CO_2 emissions using the construction project schedule information. Meanwhile, Chun and Kim (2012) developed a measurement method for CO_2 emissions from construction equipment using ZigBee sensor, whilst Choi *et al.* (2010) conducted a study on energy consumption and the estimation of CO_2 from re-bar production, and Heo and Park (2020) published a comparative analysis of life cycle carbon emissions from different structures and in the case of buildings with alternative structural designs. However, it was found that the research aimed at compiling or establishing guidelines for the classification of greenhouse gas emission sources and calculation standards (methods) of specific medium and large project units remained insufficient. Therefore, this study aims to establish guidelines for the calculation of greenhouse gas emissions through the detailed analysis of individual research projects for KIGAM basic projects.

METHODOLOGY OF ESTIMATING GREENHOUSE GAS EMISSIONS IN GEO-TECHNOLOGY

Methodology

In this study, the Guidelines for Greenhouse Gas/Energy Statement of Goal Management (Korea Environment Corporation, 2015a, 2015b, 2015c, 2015d, 2015e) Guidelines for the operation, etc. of greenhouse gas and energy target management in the public sector (Ministry of Environment Notice No. 2012-22; Ministry of Environment, 2012) Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2022), Guidelines for Building Greenhouse Gas Inventory for Universities (Korea Environment Corporation, 2011) and Guidelines for Calculating Greenhouse Gas Emissions by Local Governments, (KECO (2017)-RF10-21; Korea Environment Corporation, 2017) were applied.

The gases related to greenhouse gas emissions were selected as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrogen fluoride (HFCs), perfluorocarbon (PFCs), and sulfur hexafluoride (SF_6). The Global Warming Potential (GWP) applied the second evaluation report of IPCC (IPCC, 2022). The GWP of greenhouse gas is the ratio of 1 kg of greenhouse gas to 1 kg of CO_2 for a certain period of time (usually based on 100 years) on global warming. The GWP of greenhouse gas was CO_2: 1, CH_4: 21, N_2O: 310, HFCS: 150-11,700,

and PFCS: 6,500-9,200.

Activity Data (AD) is a scale of human activity that causes greenhouse gas emissions and is considered greenhouse gas such as fuel use and waste discharge, with the value of activity data is rounded from 4 decimal places to 3 digits. The emission factor (EF) was determined as a coefficient representing the amount of greenhouse gas emissions generated per unit activity data, such as unit fuel usage.

Boundary and Scope

The boundaries for the calculation of greenhouse gas emissions, including internal and external research and exploration activities of KIGAM, consisted of commuting, business trips, vessel leases, vehicle leases, and various participating researchers (regular workers, non-regular workers, student researchers, daily workers, domestic experts, and overseas experts, etc.). However, research projects entrusted to the outside and requests for external analysis were excluded (Table 1).

The emissions classification (Scope) divided the emissions sources included in the calculation of greenhouse gas emissions into direct emissions (Scope 1), indirect emissions (Scope 2), and other emissions (Scope 3). Direct emissions (Scope 1) was the source of direct emissions and absorption of greenhouse gases, whilst indirect emissions (Scope 2) was regarded as the case where greenhouse gases were not emitted in the consumption stage, although greenhouse gases were emitted during the production stage. In addition, for other emissions (Scope 3), this deviated from the classification of existing guidelines, and greenhouse gas emissions were calculated through the activities of participating researchers. The calculation grade (Tier) was calculated using the carbon emissions coefficient for each fuel proposed by the IPCC in consideration of the emissions estimation according to the budget details of the research plan.

Calculation Formula for Greenhouse Gas Emissions

Greenhouse gas emissions were calculated based on the characteristics of the R&D project and the research plan. Greenhouse gas emissions were calculated by multiplying activity data (AD), emission factor (EF), and global warming potential (GWP) (Fig. 1).

Derivation of the Concept of Greenhouse Gas Emission Source for Basic Projects of the KIGAM

In this study, the concepts of each emission source for the basic projects of the KIGAM were derived. The direct emission sources were fixed direct combustion, generator fuel combustion, vessel fuel combustion, gasoline combustion, and direct use of CO_2.

Table 1. R&D Activities Boundary and Scope for Basic Projects of the KIGAM

Boundary and Scope	Exceptions
· Experiment and survey	
· Commuting, business trip, vessel leases, and vehicle leases	· Requests for external analysis
· Number of people (regular workers, non-regular workers, student researchers, daily workers, domestic experts, and overseas experts)	· Research projects entrusted to the outside

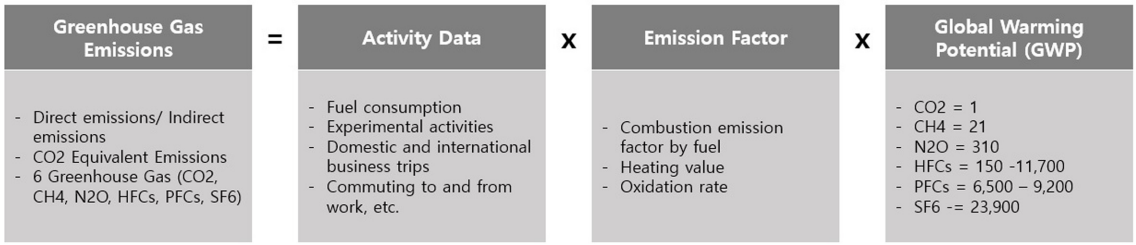

Fig. 1. Greenhouse Gas Emissions Estimation Calculation.

Meanwhile, the indirect emission sources were nitric acid, ammonia, aluminum, magnesium, and methanol use. Additionally, the other emission sources were commuting of researchers, domestic business trips, overseas business trips, overseas training, invitation of domestic experts, invitation of foreign experts, electricity use, water use, waste discharge, vessel leases, equipment, and crane leases (Table 2).

A CASE STUDY ON THE ESTIMATION OF GREENHOUSE GAS EMISSIONS FROM THE KIGAM'S BASIC PROJECTS

As a result of calculating greenhouse gas emissions for basic research projects, the total greenhouse gas emissions were 2,041.506 tCO2eq, with direct emissions of 793.235 tCO2eq, indirect emissions of 305.647 tCO2eq, and other sources of emissions of

Table 2. Derivation on the Concept of Greenhouse Gas Emission Source for Basic Projects of the KIGAM in FY 2022

Emission source	Emission source description	Remarks
Stationary combustion	· Emissions from the combustion of fuel used for experimental or heating purposes. *(Matters to be considered) Calculation of emissions based on usage of the relevant research project details.	Direct emissions
Moving combustion	· Emissions from fuel combustion in transportation, such as outdoor geological surveys. · Vehicle leases, vessel leases, equipment transportation, sample transportation, crane lease. *(Matters to be considered) Calculation of emissions based on usage of the relevant research project details.	Direct emissions
Electricity use	· Greenhouse gases are not emitted during the consumption stage, but they are indirectly emitted, since greenhouse gases are emitted from energy use during the electricity production stage. *(Matters to be considered) KIGAM's total electricity usage divided by the number of employees was converted into the corresponding participation rate for the basic project from the average annual usage per person.	Indirect emissions
Water use	· Greenhouse gases are not emitted during the consumption stage, but are indirectly discharged, since greenhouse gases are emitted due to power use during the water supply production stage. *(Matters to be considered) KIGAM's total annual water usage was converted from the average annual usage per person divided by the number of employees into the corresponding participation rate for the basic project.	Indirect emissions
Waste discharge	· Waste discharged from the lab and generated at work. *(Matters to be considered) KIGAM's total annual waste volume divided by the number of employees was converted into the participation rate for the basic project from the average annual waste volume per person.	Indirect emissions
Commuting of researchers	· Emissions from individual vehicles when commuting by participating researchers. *(Matters to be considered) Based on gasoline vehicles, 260 days a year, the rate of participation was applied, and a daily commute of 20 km was taken into account (average employee commuting distance was applied). Full-time, non-regular, and day-to-day jobs.	Other emissions
Business trip	· Calculation of emissions based on public transportation due to business trips using various means of transportation. *(Matters to be considered) Public transportation in Korea, ktx Seoul-Daejeon standard, and air mileage distance standard for overseas business trips. Domestic business trips (within 4 hours or more), intercity business trips, and overseas business trips. Full-time, non-regular and day-to-day jobs, etc.	Other emissions
Direct use of greenhouse gas	· Calculation by considering greenhouse gases used for experimental purposes as an indirect emission source. *(Matters to be considered) Ammonia, carbonate, carbide, nitric acid, adipic acid, caprotactam, magnesium, lubricant, paraffin wax, aluminum, fluorine compound use, aerosol, etc.	

942.624 tCO2eq. Since greenhouse gas emissions varied by project depending on the participating researchers, input budgets, and research field characteristics, it was important to give significance to the differences in emissions according to research activity characteristics, rather than simply considering the size of emissions by project. The research projects with the highest levels of greenhouse gas emissions from direct emission sources were in the order: 'Gas hydrate exploration and production research (281.746 tCO2eq)', 'Development of the integrated geophysical survey and real-scale data processing technologies for 3D high–resolution imaging of the marine subsurface (138.669 tCO2eq)', 'Technology development for storage efficiency improvement and safety assessment of CO_2 geological storage (124.617 tCO2eq)', and 'Geological survey in the Korean Peninsula and publication of the geological maps (112.571 tCO2eq)'. Additionally, the research projects with the highest greenhouse gas emissions from indirect emissions were in the order: 'Research in active tectonics and development of fault segment model for intraplate regions (83.705 tCO2eq)', 'Development of local biogeomaterials and commercialization technology (83.700 tCO2eq)', and 'Development of concentration, refining, and utilization processes for domestic vanadium ore (61.720 tCO2eq)'. Furthermore, the research projects with the highest greenhouse gas emissions from other sources were in the order: 'Basic researches in application and development of geological samples and geo-technology R&D policy/dissemination (89.418 tCO2eq)', 'Development of concentration, refining, and utilization processes for domestic vanadium ore (71.122 tCO2eq)', 'Geological survey in the Korean Peninsula and publication of the geological maps (58.102 tCO2eq)', and 'Development of precise exploration technology for energy storage minerals existing in Korea and the resources estimation (53.891 tCO2eq)' (Table 3).

Greenhouse gas emissions from direct emission sources were calculated as 793.235 tCO2eq (38.86%), whilst greenhouse gas emissions from indirect sources were 305.647 tCO2eq (14.97%), and greenhouse gas emissions from other sources were calculated as 942.624 tCO2eq (46.18%). Among the 793.235 tCO2eq of greenhouse gas emissions from direct emission sources, 395.675 tCO2eq was a result of vessel fuel consumption, 29.914 tCO2eq from gasoline consumption, and 173.636 tCO2eq from the direct use of CO2. Additionally, among the 305.647 tCO2eq of greenhouse gas emissions originating from indirect emission sources, nitric acid use accounted for the majority, with 301.179 tCO2eq. Furthermore, among the other sources of greenhouse gas emissions totaling 942.624 tCO2eq, emissions from commuting researchers were 451.051 tCO2eq, whilst emissions from overseas business trips were 193.1629 tCO2eq, emissions from domestic business trips were 160.2869 tCO2eq, and emissions from invitation of overseas experts were 65.399 tCO2eq (Table 4).

Of the total 793.235 tCO2eq from direct emissions in basic projects, emissions due to direct combustion for air conditioning and heating amounted to 173.636 tCO2eq, whilst emissions from generator fuel consumption were 3.210 tCO2eq, emissions from vessel fuel consumption totaled 395.675 tCO2eq, emissions from gasoline consumption were 219.914 tCO2eq, and the direct use of CO2 for experimental performance contributed 0.8 tCO2eq. Greenhouse gas emissions due to direct combustion for air conditioning and heating were as follows from projects with high emissions. 'Development of concentration, refining, and utilization processes for domestic vanadium ore (17.204 tCO2eq)', 'Geological survey in the Korean Peninsula and publication of the geological maps (12.908 tCO2eq)', 'Research into rock properties in the deep environment for HLW geological disposal (12.908 tCO2eq)', 'Development of climate change adaption technologies for securing and utilizing large-scale groundwater resources (11.254 tCO2eq)', and 'Development of precise exploration technology for energy storage minerals in Korea and resource estimation (11.083 tCO2eq)'. The research projects with the highest levels of greenhouse gas emissions from vessel fuel consumption were in the order: 'Development of the integrated geophysical survey and real-scale data processing technologies for 3D high–resolution imaging of the marine

Table 3. Calculation results for greenhouse gas emissions from basic projects of the KIGAM in FY 2022

Projects	Project No.	Calculation of Greenhouse Gas Emissions (tCO2eq)			
		Direct emissions	Indirect emissions	Other sources	Total
Geological survey in the Korean Peninsula and publication of the geological maps	1-1	112.571	0.006	58.102	170.679
Research on Rock Properties in Deep Environment for HLW Geological Disposal	1-2	12.908		42.436	45.209
Integrated management and harm assessment of potentially hazardous elements from geological bedrock in Korea	1-3	4.014		15.681	19.695
Development of integrated geophysical monitoring system at depth for assessing Earthquake and fault activities at South-eastern Korea	1-4	3.590		17.829	21.419
Development of dynamic rupture based strong ground motion prediction and region-specific earthquake early warning techniques in Southeastern Korea	1-5	4.069		33.218	37.287
Development of techniques for precise seismicity tracking and integrated seismic data management	1-6	10.155		33.919	44.074
Research in active tectonics and development of fault segment model for intraplate regions	1-7	4.782	83.705	49.164	137.651
Evaluation of active volcano characteristics on the Korean Peninsula and development of basic volcanic monitoring technology	1-8	2.940	2.255	11.164	16.359
Development of GeoAI platform for the utilization of artificial intelligence and big data in geoscience	1-9	1.433		7.337	8.770
Establishment of National Geoscience Data Center (NGDC) infra through development of geo-big data open platform	1-10	4.551		18.657	23.208
Diversification and efficiency on testing, identifying, and analyzing geo-resource Material	1-11	6.498		20.295	26.793
Basic research into the application and development of geological samples and geo-technology R&D policy/dissemination	1-12	8.574		89.418	97.992
Development of precise exploration technology for energy storage minerals (V) in Korea and resource estimation	2-1	11.083		53.891	64.974
Development of concentration, refining, and utilization processes for domestic vanadium ore	2-2	17.204	61.720	71.122	150.046
Development of local bio-geomaterials and commercialization technology	2-3	52.852	83.700	14.156	150.708
Development of a fluid-dynamic control reactor for the high value-added materialization of mineral resources and its applications	2-4	1.323	11.160	5.210	17.693
A study on the master plan for cooperation in Northern resources and strategy for evaluation of cooperation projects	2-5	2.604		9.010	11.614
Development of a novel and environmentally-sound process for the recovery of metals and elemental sulfur from nickel ore	2-6	1.755	22.826	9.576	34.157
Petroleum system evaluation in Korean shelf area and development of shale EGR+ methods	3-1	5.580	0.805	50.675	57.060
Development of core technology for in-line type multi-phase (water-oil-gas) flow separation to improve the efficiency of resource production in subsea oil and gas fields	3-2	0.851		4.077	4.928
Development of integrated geophysical survey and real-scale data processing technologies for 3D high-resolution imaging of the marine subsurface	3-3	138.669		36.820	175.489

Table 3. Continued

Projects	Project No.	Calculation of Greenhouse Gas Emissions (tCO2eq)			
		Direct emissions	Indirect emissions	Other sources	Total
Research into safety management of R/V Tamhae2 and development of near-shore surveying methods	3-4	5.124		9.123	14.247
Study on concentration and enrichment mechanisms of rare-earth elements in deep-sea sediments of the Pacific	3-5	1.237		12.821	14.058
Gas hydrate exploration and production research	3-6	218.746	13.942	17.810	271.778
Development of climate change adaption technologies for securing and utilizing large-scale groundwater resources	4-1	11.254		47.180	58.434
Development of landslide early warning technologies with real-time data in urban area and risk management technology for potentially harmful Geogenic elements	4-2	8.871	11.301	35.240	55.412
Development of technologies for an integrated smart solution to actively respond to complex urban geo-hazards	4-3	2.379		9.901	12.280
Development of urban geological survey and real-time monitoring technologies using traffic noise	4-4	0.767		8.194	8.961
Paleohydroclim with the highest amount of greenhouse gas emissions from indirect sources ate variability and extreme event study	4-5	0.708		5.055	5.763
Technology development for storage efficiency improvement and safety assessment of CO_2 geological storage	4-6	124.617		36.373	160.990
Development of deep subsurface characterization technology for the utilization of deep underground space	4-7	4.157		40.262	44.419
Identification of the reaction pathway of $CaCO_3$ and $MgCO_3$ including prenucleation	4-8	1.961	13.971	8.694	24.626
Evaluation of the controlling factors in multiphase flow using 4D synchrotron X-ray imaging	4-9	1.145		4.590	5.735
Development of rare-earth element concentrating technology from coal fly ash by applying high-ionic strength leaching and mineral carbonation	4-10	2.026		6.809	8.835
Development of biomass-graphene manufacturing technology for energy storage through flash pyrolysis	9-1	0.464	0.160	9.759	10.383
Tracking the emergence of the first human on the Korean Peninsula	9-2	0.677		7.454	8.131
Centrifuge model test and computational model development of critical continuous rainfall amounts triggering landslide initiations in natural slopes	9-3	0.533		3.319	3.852
Source technology development for securing geomaterial-dedicated AI Hybrid CT	9-4	0.194		4.489	4.683
Development of lithium recovery technology from a low-grade salt lake by an electric adsorption process	9-5	0.369	0.096	2.514	2.979
Total		793.235	305.647	942.624	2,041.506

subsurface (131.526 tCO2eq)', 'Technology development for storage efficiency improvement and safety assessment of CO2 geological storage (118.374 tCO2eq)', 'Geological survey in the Korean Peninsula and publication of the geological maps (96.453 tCO2eq)', and 'Development of local bio-geomaterials and commercialization technology (49.322 tCO2eq)'. Additionally, greenhouse gas emissions from gasoline consumption were: 'Gas hydrate exploration and production research (215.602 tCO2eq)' and 'Research on safety management

Table 4. Results of calculation of greenhouse gas emissions by basic project by emission source of the KIGAM in FY 2022

	Emission source	Emissions (tCO2eq)	Ratio (%)
Direct emissions	Direct combustion for air conditioning and heating	173.636	8.51
	Generator fuel consumption	3.210	0.16
	Vessel fuel consumption	395.675	19.38
	Gasoline consumption	219.914	10.77
	Direct use of CO_2	0.8	0.04
	Sub-total	793.235	38.86
Indirect emissions	Nitric acid consumption	301.179	14.75
	Ammonia consumption	3.786	0.19
	Aluminum consumption	0.545	0.03
	Magnesium consumption	0.099	0.00
	Methanol consumption	0.038	0.00
	Sub-total	305.647	14.97
Other sources	Commuting of researchers	451.051	22.10
	Domestic business trip	160.286	7.85
	Overseas business trip	193.162	9.46
	Overseas training	14.692	0.72
	Invitation of domestic experts	9.946	0.49
	Invitation of foreign experts	65.399	3.20
	Electricity use	15.271	0.75
	Water use	11.235	0.55
	Waste Discharge	9.782	0.48
	Vessel leases	8.988	0.44
	Equipment leases	2.583	0.13
	Crane leases	0.229	0.01
	Sub-total	942.624	46.17
Total		2,041.506	100.00

of R/V Tamhae 2 and development of near-shore surveying methods (4.312 tCO2eq)' (Table 5).

Of the total indirect emissions of 305.647 tCO2eq from the KIGAM's basic projects, greenhouse gas emissions from nitric acid use contributed 301.179 tCO2eq, whilst emissions from ammonia were 3.786 tCO2eq, aluminum emissions totaled 0.545 tCO2eq, magnesium emissions were 0.099 tCO2eq, and methanol emissions were 0.038 tCO2eq (Table 6).

Other greenhouse gas emissions from basic projects totaled 942.624 tCO2eq. Of this total, 451.051 tCO2eq was emitted by private cars when researchers were commuting, with a further 160.286 tCO2eq being emitted by transportation for domestic business trips, 193.162 tCO2eq from aircrafts for overseas business trips, and 14.692 tCO2eq being emitted as a result of overseas education and training. Emissions due to the invitation of domestic experts contributed 9.946 tCO2eq, whilst the greenhouse gas emissions from the invitation of foreign experts was 65.399 tCO2eq. In addition, greenhouse gas emissions from electricity use totaled 15.271 tCO2eq, emissions from water use contributed 11.235 tCO2eq, 9.782 tCO2eq from waste emissions, 8.988 tCO2eq from vessel leases, 2.583 tCO2eq from equipment or sample transportation, and 0.229 tCO2eq from crane leases (Table 7).

Greenhouse gas emissions from KIGAM's basic projects averaged 2.11 tCO2eq per 100 million won.

Table 5. Calculation results of greenhouse gas emissions from direct emission sources from basic projects of KIGAM in FY 2022

Project No.	Calculation of Greenhouse Gas Emissions from Direct Emissions (tCO2eq)					
	Direct combustion	Generator fuel	Vessel fuel	Gasoline	Direct use of CO_2	Total
1-1	12.908	3.210	96.453			112.571
1-2	12.908					12.908
1-3	4.014					4.014
1-4	3.590					3.590
1-5	4.069					4.069
1-6	10.155					10.155
1-7	4.782					4.782
1-8	2.940					2.940
1-9	1.433					1.433
1-10	4.551					4.551
1-11	6.498					6.498
1-12	8.574					8.574
2-1	11.083					11.083
2-2	17.204					17.204
2-3	3.530		49.322			52.852
2-4	1.323					1.323
2-5	2.604					2.604
2-6	1.755					1.755
3-1	5.580					5.580
3-2	0.851					0.851
3-3	7.143		131.526			138.669
3-4	0.812			4.312		5.124
3-5	1.237					1.237
3-6	3.144			215.602		218.746
4-1	11.254					11.254
4-2	8.871					8.871
4-3	2.379					2.379
4-4	0.767					0.767
4-5	0.708					0.708
4-6	5.843		118.374		0.400	124.617
4-7	4.157					4.157
4-8	1.561				0.400	1.961
4-9	1.145					1.145
4-10	2.026					2.026
9-1	0.464					0.464
9-2	0.677					0.677
9-3	0.533					0.533
9-4	0.194					0.194
9-5	0.369					0.369
Total	173.636	3.210	395.675	219.914	0.8	793.235

※ Refer to Table 3 for the project title.

Table 6. Calculation results of greenhouse gas emissions from indirect emission sources from basic projects of the KIGAM in FY 2022

Project No.	Calculation of Greenhouse Gas Emissions from Indirect Emissions (tCO2eq)					
	Nitric acid	Ammonia	Aluminum	Magnesium	Methanol	Total
1-1	0.002	0.004				0.006
1-2						
1-3						
1-4						
1-5						
1-6						
1-7	83.700		0.005			83.705
1-8	2.251	0.004				2.255
1-9						
1-10						
1-11						
1-12						
2-1						
2-2	61.380		0.241	0.099		61.720
2-3	83.700					83.700
2-4	11.160					11.160
2-5						
2-6	22.520	0.268	0.038			22.826
3-1		0.805				0.805
3-2						
3-3						
3-4						
3-5						
3-6	11.258	2.684				13.942
4-1						
4-2	11.258		0.005		0.038	11.301
4-3						
4-4						
4-5						
4-6						
4-7						
4-8	13.950	0.021				13.971
4-9						
4-10						
9-1			0.160			0.160
9-2						
9-3						
9-4						
9-5			0.096			0.096
Total	301.179	3.786	0.545	0.099	0.038	305.647

※ Refer to Table 3 for the project title.

Table 7. Calculation results of greenhouse gas emissions from other sources of emissions from basic projects of the KIGAM in FY 2022

Project No.	Calculation of Greenhouse Gas Emissions from Other Sources (tCO2eq)												
	Commuting of researchers	Domestic business trip	Overseas business trip	Overseas training	Invitation of domestic experts	Invitation of foreign experts	Electricity use	Water use	Waste Discharge	Vessel leases	Equip. leases	Crane leases	Total
1-1	35.061	14.212	0.222		0.317	0.174	1.186	0.875	0.766	4.292	0.982	0.015	58.102
1-2	7.532	22.287	11.923		0.086		0.255	0.188	0.165				42.436
1-3	10.903	3.666			0.058		0.369	0.272	0.238	0.175			15.681
1-4	9.751	3.810			0.038	3.445	0.330	0.243	0.212				17.829
1-5	11.051	4.344	2.881		0.096	3.955	0.374	0.276	0.241				33.218
1-6	26.771	3.060	1.776		0.154		0.905	0.668	0.585				33.919
1-7	2.989	14.152	18.004		0.250	2.722	0.439	0.324	0.284				49.164
1-8	7.984	2.181	0.222		0.134		0.270	0.199	0.174				11.164
1-9	3.892	2.862			0.269		0.132	0.097	0.085				7.337
1-10	2.362	4.952			0.346		0.418	0.309	0.270				18.657
1-11	17.650	0.835		0.367	0.019		0.597	0.441	0.386				20.295
1-12	23.288	3.869	28.766		0.778	30.849	0.789	0.570	0.509				89.418
2-1	30.101	3.572	17.368		0.423		1.018	0.751	0.658				53.891
2-2	46.726	6.294	9.781		1.533	2.260	1.573	1.167	1.020		0.768		71.122
2-3	9.589	3.665			0.130		0.324	0.239	0.209				14.156
2-4	3.594	1.284			0.041		0.122	0.090	0.079				5.210
2-5	7.072	1.281			0.086		0.239	0.177	0.155				9.010
2-6	4.766	0.479	3.889		0.058		0.161	0.119	0.104				9.576
3-1	15.155	5.400	23.404	2.881	0.230	2.380	0.516	0.378	0.331				50.675
3-2	2.312	1.485			0.094		0.078	0.058	0.050				4.077
3-3	19.401	1.922	8.414	5.252	0.267		0.656	0.484	0.424				36.820
3-4	2.205	2.133			0.086		0.075	0.055	0.048	4.521			9.123
3-5	3.359	0.393	8.644		0.154	0.114	0.084	0.073					12.821
3-6	7.862	1.113	7.961		0.240		0.266	0.196	0.172				17.810
4-1	30.566	10.908	1.082		0.576	1.583	1.034	0.763	0.668				47.180
4-2	24.097	8.577			0.623		0.815	0.601	0.527				35.240
4-3	6.462	2.457			0.461		0.219	0.161	0.141				9.901
4-4	2.085	0.864	5.009		0.067		0.071	0.052	0.046				8.194
4-5	1.924	2.880			0.096		0.065	0.048	0.042				5.055
4-6	15.871	4.041	14.517		0.173		0.537	0.396	0.347		0.491		36.373
4-7	11.290	8.956	10.637	5.458	0.422	2.588	0.382	0.282	0.247				40.262
4-8	4.239	1.275			0.250	2.588	0.143	0.106	0.093				8.694
4-9	3.111	1.065			0.163		0.105	0.078	0.068				4.590
4-10	5.502	0.720			0.144		0.186	0.137	0.120				6.809
9-1	1.260	1.440	6.890		0.067		0.043	0.031	0.028				9.759
9-2	1.839	2.496			0.230	2.741	0.062	0.046	0.040				7.454
9-3	1.449	1.005			0.192		0.049	0.036	0.032		0.342	0.214	3.319
9-4	0.528	0.480	3.323		0.115		0.018	0.013	0.012				4.489
9-5	1.289	1.044			0.077		0.044	0.032	0.028				2.514
Total	451.051	160.286	193.162	14.692	9.946	65.399	15.271	11.235	9.782	8.988	2.583	0.229	942.624

※ Refer to Table 3 for the project title.

Table 8. Results of calculating greenhouse gas emissions per 100 million won from basic projects of the KIGAM in FY 2022

Title	Project No.	2022 Budget (mill. Won) (A)	Emissions (tCO2eq) (B)	Emissions per 100 mill. Won (tCO2eq) (B/A)
Geological survey in the Korean Peninsula and publication of the geological maps	1-1	6,613	170.679	2.58
Research on Rock Properties in Deep Environment for HLW Geological Disposal	1-2	2,204	55.344	2.51
Integrated management and harm assessment of potentially hazardous elements from geological bedrock in Korea	1-3	2,061	19.695	0.96
Development of integrated geophysical monitoring system at depth for assessing Earthquake and fault activities in South-eastern Korea	1-4	6,018	21.419	0.36
Development of dynamic rupture-based strong ground motion prediction and region-specific earthquake early warning techniques in Southeastern Korea	1-5	2,590	37.287	1.44
Development of techniques for precise seismicity tracking and integrated seismic data management	1-6	6,179	44.074	0.71
Research into active tectonics and development of fault segment model for intraplate regions	1-7	2,600	137.651	5.29
Evaluation of active volcanoes characteristics on the Korean Peninsula and development of basic volcano monitoring technology	1-8	1,359	16.359	1.20
Development of GeoAI platform for the utilization of artificial intelligence and big data in geoscience	1-9	1,176	8.77	0.75
Establishment of National Geoscience Data Center (NGDC) infra through development of geo-big data open platform	1-10	2,167	23.208	1.07
Diversification and efficiency on testing, identifying, and analyzing geo-resource Material	1-11	3,293	26.793	0.81
Basic research into the application and development of geological samples and geo-technology R&D policy/dissemination	1-12	3,604	97.992	2.72
Development of precise exploration technology for energy storage minerals (V) in Korea and resource estimation	2-1	4,564	64.974	1.42
Development of concentration, refining, and utilization processes for domestic vanadium ore	2-2	7,548	150.046	1.99
Development of local bio-geomaterials and commercialization technology	2-3	2,282	150.708	6.60
Development of a fluid-dynamic control reactor for the high value-added materialization of mineral resources and its application	2-4	504	17.693	3.51
A study on the master plan for cooperation in Northern resources and the strategy for evaluation of cooperation projects	2-5	920	11.614	1.26
Development of a novel and environmentally-sound process for the recovery of metals and elemental sulfur from nickel ore	2-6	691	34.157	4.94
Petroleum system evaluation in Korean shelf area and development of shale EGR+ methods	3-1	2,964	57.060	1.93
Development of core technology for in-line type multi-phase (water-oil-gas) flow separation to improve the efficiency of resource production in subsea oil and gas fields	3-2	301	4.928	1.64
Development of the integrated geophysical survey and real-scale data processing technologies for 3D high–resolution imaging of the marine subsurface	3-3	4,309	175.489	4.07

Table 8. Continued

Title	Project No.	2022 Budget (mill. Won) (A)	Emissions (tCO2eq) (B)	Emissions per 100 mill. Won (tCO2eq) (B/A)
Research on safety management of R/V Tamhae2 and development of near-shore surveying methods	3-4	1,712	14.2474	0.83
Study on concentration and enrichment mechanisms of rare-earth elements in deep-sea sediments of the Pacific	3-5	408	14.058	3.45
Gas hydrate exploration and production research	3-6	7,287	271.778	3.73
Development of climate change adaption technologies for securing and utilizing large-scale groundwater resources	4-1	4,783	58.434	1.22
Development on landslide early warning technologies with real-time data in urban area and risk management technology for potentially harmful geogenic elements	4-2	4,009	55.412	1.38
Development of technologies for an integrated smart solution to actively respond to complex urban geo-hazards	4-3	2,028	12.28	0.61
Development of urban geological survey and real-time monitoring technologies using traffic noise	4-4	389	8.961	2.30
Paleohydro-climate variability and extreme event study	4-5	455	5.763	1.27
Technology development for storage efficiency improvement and safety assessment of CO_2 geological storage	4-6	3,897	160.99	4.13
Development of deep subsurface characterization technology for the utilization of deep underground space	4-7	3,344	44.419	1.33
Identification of the reaction pathway for $CaCO_3$ and $MgCO_3$ including prenucleation	4-8	856	24.626	2.88
Evaluation of the controlling factors in multiphase flow using 4D synchrotron X-ray imaging	4-9	741	5.735	0.77
Development of rare-earth element concentrating technology from coal fly ash by applying high-ionic strength leaching and mineral carbonation	4-10	693	8.835	1.27
Development of biomass-graphene manufacturing technology for energy storage through flash pyrolysis	9-1	505	10.383	2.06
Tracking the emergence of the first human on the Korean Peninsula	9-2	451	8.131	1.80
Centrifuge model test and computational model development of critical continuous rainfall amounts triggering landslide initiations in natural slopes	9-3	556	3.852	0.69
Source technology development for securing geomaterial-dedicated AI Hybrid CT	9-4	204	4.683	2.30
Development of lithium recovery technology from low-grade salt lake by electric adsorption process	9-5	396	2.979	0.75
Total		96,661	2,041.506	2.11

The projects that emitted the most greenhouse gases per 100 million won were in the following order of magnitude, from most to least: ‘Development of local bio-geomaterials and commercialization technology (6.60 tCO2eq)’, ‘Research in active tectonics and development of fault segment model for intraplate regions (5.29 tCO2eq)’, ‘Development of a novel and environmentally-sound process for the recovery of metals and elemental sulfur from nickel ore (4.94 tCO2eq)’ and ‘Technology development for storage efficiency improvement and safety assessment of CO_2 geological storage (4.13 tCO2eq)’.

Table 9. Results of calculating greenhouse gas emissions per person (100% participation rate) for basic projects from KIGAM in FY 2022.

Title	Project No.	participation (명) (A)	Participation rate (%) (B)	Sum (%) (C = A*B)	Emissions (tCO2eq) (D)	Emissions per capita (tCO2eq) (D/C)
Geological survey in the Korean Peninsula and publication of the geological maps	1-1	98	32.77	3210.67	170.679	5.316
Research into Rock Properties in Deep Environment for HLW Geological Disposal	1-2	26	26.53	689.78	55.344	8.023
Integrated management and harm assessment of potentially hazardous elements from geological bedrock in Korea	1-3	32	31.2	998.4	19.695	1.973
Development of integrated geophysical monitoring system at depth for assessing Earthquake and fault activities in South-eastern Korea	1-4	29	30.79	892.91	21.419	2.399
Development of dynamic rupture-based strong ground motion prediction and region-specific earthquake early warning techniques in Southeastern Korea	1-5	23	44.00	1012.00	37.287	3.684
Development of techniques for precise seismicity tracking and integrated seismic data management	1-6	47	52.16	2451.52	44.074	1.798
Research into active tectonics and the development of a fault segment model for intraplate regions	1-7	30	39.65	1189.5	137.651	11.572
Evaluation of active volcano characteristics on the Korean Peninsula and development of basic volcanic monitoring technology	1-8	18	40.62	731.16	16.359	2.237
Development of GeoAI platform for the utilization of artificial intelligence and big data in geoscience	1-9	10	35.64	356.40	8.77	2.461
Establishment of National Geoscience Data Center (NGDC) infra through development of geo-big data open platform	1-10	38	29.79	1132.02	23.208	2.050
Diversification and efficiency in testing, identifying, and analyzing geo-resource materials	1-11	31	52.14	1616.34	26.793	1.658
Basic research into the application and development of geological samples and geo-technology R&D policy/dissemination	1-12	40	53.32	2132.62	97.992	4.595
Development of precise exploration technology for energy storage minerals (V) in Korea and resource estimation	2-1	55	56.24	2756.49	64.974	2.357
Development of concentration, refining, and utilization processes for domestic vanadium ore	2-2	78	54.86	4278.89	150.046	3.507
Development of local bio-geomaterials and commercialization technology	2-3	30	29.27	878.10	150.708	17.163
Development of a fluid-dynamic control reactor for the high value-added materialization of mineral resources and its application	2-4	8	41.14	329.12	17.693	5.376
A study on the master plan for cooperation in Northern resources and the strategy for evaluation of cooperation projects	2-5	10	64.76	647.60	11.614	1.793
Development of a novel and environmentally-sound process for the recovery of metals and elemental sulfur from nickel ore	2-6	8	54.56	436.48	34.157	7.826
Petroleum system evaluation in Korean shelf area and development of shale EGR+ methods	3-1	30	46.26	1387.80	57.06	4.112
Development of core technology for in-line type multi-phase (water-oil-gas) flow separation to improve the efficiency of resource production in subsea oil and gas fields	3-2	6	35.28	211.68	4.928	2.328

Table 9. Continued

Title	Project No.	participation (명) (A)	Participation rate (%) (B)	Sum (%) (C = A*B)	Emissions (tCO2eq) (D)	Emissions per capita (tCO2eq) (D/C)
Development of integrated geophysical survey and real-scale data processing technologies for 3D high–resolution imaging of the marine subsurface	3-3	60	29.61	1776.60	175.489	9.878
Research on safety management of R/V Tamhae2 and development of near-shore surveying methods	3-4	24	43.10	1034.40	14.2474	1.377
Study on the concentration and enrichment mechanisms of rare-earth elements in deep-sea sediments of the Pacific	3-5	9	34.18	307.62	14.058	4.570
Gas hydrate exploration and production research	3-6	73	24.21	1766.98	271.778	15.381
Development of climate change adaption technologies for securing and utilizing large-scale groundwater resources	4-1	46	60.85	2799.10	58.434	2.088
Development on landslide early warning technologies with real-time data in urban area and risk management technology for potentially harmful geogenic elements	4-2	41	53.82	2206.61	55.412	2.511
Development of technologies for an integrated smart solution to actively respond to complex urban geo-hazards	4-3	21	28.18	591.78	12.28	2.075
Development of urban geological survey and real-time monitoring technologies using traffic noise	4-4	7	27.27	190.89	8.961	4.694
Paleohydro-climate variability and extreme event study	4-5	9	19.58	176.22	5.763	3.270
Technology development for storage efficiency improvement and safety assessment of CO2 geological storage	4-6	56	27.54	1542.24	160.99	10.439
Development of deep subsurface characterization technology for the utilization of deep underground space	4-7	24	43.08	1033.92	44.419	4.296
Identification of the reaction pathway for CaCO3 and MgCO3 including prenucleation	4-8	10	38.82	388.20	24.626	6.344
Evaluation of the controlling factors in multiphase flow using 4D synchrotron X-ray imaging	4-9	8	35.61	284.88	5.735	2.013
Development of rare-earth element concentrating technology from coal fly ash by applying high-ionic strength leaching and mineral carbonation	4-10	11	45.8	503.80	8.835	1.754
Development of biomass-graphene manufacturing technology for energy storage through flash pyrolysis	9-1	6	19.23	115.38	10.383	8.999
Tracking the emergence of the first human on the Korean Peninsula	9-2	14	12.03	168.42	8.131	4.828
Centrifuge model test and computational model development of critical continuous rainfall amounts triggering landslide initiations in natural slopes	9-3	7	18.95	132.65	3.852	2.904
Source technology development for securing geomaterial-dedicated AI Hybrid CT	9-4	5	9.67	48.35	4.683	9.686
Development of lithium recovery technology from low-grade salt lake by electric adsorption process	9-5	9	13.11	117.99	2.979	2.525
Total		1,054	40.35	42,525.51	2,041.506	4.800

In contrast, the basic projects from KIGAM that emitted the least greenhouse gases per 100 million won was as follows, from the least to most: 'Development of integrated geophysical monitoring system

at depth for assessing earthquake and fault activities in South-eastern Korea (0.36 tCO2eq)', 'Development of technologies for an integrated smart solution to actively respond to complex urban geo-hazards (0.61 tCO2eq)', 'Centrifuge model test and computational model development of critical continuous rainfall amounts triggering landslide initiations in natural slopes (0.69 tCO2eq)', and 'Development of techniques for precise seismicity tracking and integrated seismic data management (0.71 tCO2eq)' (Table 8).

The average greenhouse gas emissions per person were 4.800 tCO2eq, based on a 100% participation rate from the total greenhouse gas emissions of 2,041.506 tCO2eq from KIGAM's basic projects. The highest project per capita greenhouse gas emissions of the basic research projects were as follows: 'Development of local bio-geomaterials and commercialization technology (17.163 tCO2eq)', 'Gas hydrate exploration and production research (15.381 tCO2eq)', 'Research into active tectonics and the development of a fault segment model for intraplate regions (11.572 tCO2eq)', 'Technology development for storage efficiency improvement and safety assessment of CO_2 geological storage (10.439 tCO2eq)', 'Development of the integrated geophysical survey and real-scale data processing technologies for 3D high–resolution imaging of the marine subsurface (9.878 tCO2eq)', and 'Source technology development for securing geomaterial-dedicated AI Hybrid CT (9.686 tCO2eq)' (Table 9).

Of the total 2,041.506 tCO2eq from KIGAM's basic projects, researchers commuting was the highest emission source, followed by vessel leases, nitric acid use, gasoline consumption, overseas business trip, direct combustion, domestic business trip, and invitations for overseas experts. Greenhouse gas emissions from participating researchers commuting totaled 451.051

Table 10. Percentage of greenhouse gas emissions by emission source from basic projects by the KIGAM in FY 2022

By emission source	Emissions (tCO2eq)	Ratio (%)	Remarks
Commuting of researchers	451.051	22.09	
Use of owned vessel	395.675	19.38	
Nitric acid use	301.179	14.75	
Gasoline Combustion	219.914	10.77	
Overseas business trip	193.162	9.46	
Direct combustion	173.636	8.51	
Domestic business trip	160.286	7.85	
Invitation of foreign experts	65.399	3.20	
Electricity use	15.271	0.75	
Overseas training	14.692	0.72	
Water use	11.235	0.55	
Invitation of domestic experts	9.946	0.49	
Waste Discharge	9.782	0.48	
Vessel leases	8.988	0.44	
Ammonia consumption	3.786	0.19	
Generator fuel consumption	3.210	0.16	
Using the Equipment	2.583	0.13	
Direct use of CO2	0.800	0.04	
Aluminum consumption	0.545	0.03	
Crane leases	0.229	0.01	
Magnesium consumption	0.099	0.00	
Methanol consumption	0.038	0.00	
Total	2,041.506	100.00	

tCO2eq, accounting for 22.09%, this being the largest contribution. Meanwhile, emissions from vessel leases accounted for 19.38% (395.675 tCO2eq), whilst emissions from nitric acid use in the laboratory were 14.75% (301.179 tCO2eq), and emissions from gasoline consumption comprised 10.77% (219.914 tCO2eq). Furthermore, emissions from overseas business trips accounted for 9.46% (193.162 tCO2eq), whilst 8.51% (173.636 tCO2eq) was a result of direct combustion by heating and cooling, 7.85% (160.286 tCO2eq) was from domestic business trips, and 3.20% (65.399 tCO2eq) originated from invitations to overseas experts (Table 10). However, the ratio of greenhouse gas emissions by these sources only demonstrated the form of emissions. Therefore, it should be understood as different research activities specialized for each research field. It should never cause problems that dampen research activities but should be understood only by the emission figures themselves.

CONCLUSION

In this study, the research plans and budget details of individual projects were analyzed to calculate the basic project greenhouse gas emissions, whilst various greenhouse gas emission scopes and boundaries were also determined here. For this, 22 greenhouse gas emission sources were derived, including direct sources, indirect sources, and other emission sources, with emissions from research activities being calculated on a trial basis by applying guidelines for calculating greenhouse gas emissions such as from the IPCC and the Ministry of Environment of Korea. Direct emissions sources included direct combustion (cooling and heating) and the use of vessel leases, whilst indirect emissions sources comprised the use of nitric acid and ammonia in experiments and outdoor field survey activities. Additionally, the other sources of emissions included commuting to and from work for research and development (R&D) activities, domestic and foreign business trips, and inviting domestic and foreign experts. As a result, KIGAM's basic project R&D activities in the fiscal year of 2022 were calculated to have produced total greenhouse gas emissions of 2,041.506 tCO2eq, of which direct emissions contributed 793.028 tCO2eq, indirect emissions comprised 305.647 tCO2eq, and other direct and indirect emissions totaled 942.624 tCO2eq.

Depending on the characteristics of the research field, R&D performance in geo-technology will be further activated and innovative research results can be obtained only after acknowledging greenhouse gas emissions. In other words, the characteristics of each project should be recognized as they are. However, regardless of the research field, perspectives such as process innovation should be considered in all projects. In the case of studies using similar reagents or materials, efforts to use reagents or materials produced by emitting as little greenhouse gas as possible and saving usage are required. It is also necessary for national R&D institutions to understand the status of greenhouse gas emissions generated when performing basic projects by government contributions and to investigate and analyze whether they recognize their contributions to greenhouse gas reduction in the expected performance or effect of the research. In order to promote contributions to greenhouse gas reduction according to institutional research activities, this study aimed to raise the awareness of researchers by identifying the size of greenhouse gas emissions from R&D activities themselves as part of the KIGAM basic project's detailed tasks.

In the basic projects of the KIGAM input budget for FY 2022 (Total 96.661 billion won), greenhouse gas emissions per 100 million won were calculated as 2.11 tCO2eq, whilst greenhouse gas emissions per participating researcher (100% participation rate) were calculated as 4.800 tCO2eq. Among the total greenhouse gas emissions of 2,041.30 tCO2eq for KIGAM's basic projects, greenhouse gas emissions by source in order of magnitude were commuting (22.10%), vessel leases (19.38%), nitric acid consumption (14.75%), gasoline consumption (10.77%), direct combustion (8.51%), domestic business trip (7.85%), and foreign expert invitation (3.20%).

Until now, the results and performance of research

projects have generally been focused on the perspective of how much they contribute to the reduction of greenhouse gases. However, as in this study, it is important to calculate greenhouse gas emissions according to the performances of basic projects at the level of one institution. The calculation of greenhouse gas emissions for these research projects should be carried out annually rather than once and accumulated for at least five years. Only then, will it will be possible to standardize emissions increase and decrease specifications due to differences in research characteristics and research methods. This will then be used to set emissions management directions and to evaluate ESG management's contribution to the environmental sector.

In the future, it will be necessary to link it to deriving indicators related to the contribution to carbon neutrality in ESG management of basic projects for research institutions. Currently, for most research projects in Korea, there are no performance-related indicators considering ESG in terms of performance indicators, performance goals, expected performance, and effects. Therefore, it is necessary to induce all basic research projects to present quantitative performance such as the level of greenhouse gas reduction. The results of calculating greenhouse gas emissions for each basic project in the fiscal year 2022 from KIGAM were set as the base year, whilst the corresponding project reduction amount is encouraged to be presented in comparison with fiscal 2022. This will result in budget savings, although in addition, efforts are needed to measure the expected performance of direct reduction in greenhouse gas emissions.

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