Journal of the Air & Waste Management Association

ISSN: 1096-2247 (Print) 2162-2906 (Online) Journal homepage: https://www.tandfonline.com/loi/uawm20

# Development of municipal solid waste classification in Korea based on fossil carbon fraction

Jeongwoo Lee, Seongmin Kang, Seungjin Kim, Ki-Hyun Kim & Eui-Chan Jeon

**To cite this article:** Jeongwoo Lee, Seongmin Kang, Seungjin Kim, Ki-Hyun Kim & Eui-Chan Jeon (2015) Development of municipal solid waste classification in Korea based on fossil carbon fraction, Journal of the Air & Waste Management Association, 65:10, 1256-1260, DOI: 10.1080/10962247.2015.1079563

**To link to this article:** https://doi.org/10.1080/10962247.2015.1079563

TECHNICAL PAPER

# Development of municipal solid waste classification in Korea based on fossil carbon fraction

Jeongwoo Lee,[1] Seongmin Kang,[2] Seungjin Kim,[3] Ki-Hyun Kim,[4] and Eui-Chan Jeon[2,*]

[1]*Department of Earth and Environmental Sciences, Sejong University, Seoul, Korea*
[2]*Department of Environment & Energy, Sejong University, Seoul, Korea*
[3]*Cooperate Course for Climate Change, Sejong University, Seoul, Korea*
[4]*Department of Civil & Environmental Engineering, Hanyang University, Seoul, Korea*
[*]*Please address correspondence to: Eui-Chan Jeon, Department of Environment & Energy, Sejong University, 98 Gunja-dong Gwangjin-gu, Seoul 143-747, Korea; e-mail: ecjeon@sejong.ac.kr*

*Environmental problems and climate change arising from waste incineration are taken quite seriously in the world. In Korea, the waste disposal methods are largely classified into landfill, incineration, recycling, etc. and the amount of incinerated waste has risen by 24.5% from 2002. In the analysis of CO2 emissions estimations of waste incinerators fossil carbon content are main factor by the IPCC. FCF differs depending on the characteristics of waste in each country, and a wide range of default values are proposed by the IPCC. This study conducted research on the existing classifications of the IPCC and Korean waste classification systems based on FCF for accurate greenhouse gas emissions estimation of waste incineration.*

*The characteristics possible for sorting were classified according to FCF and form. The characteristics sorted according to fossil carbon fraction were paper, textiles, rubber, and leather. Paper was classified into pure paper and processed paper; textiles were classified into cotton and synthetic fibers; and rubber and leather were classified into artificial and natural.*

*The analysis of FCF was implemented by collecting representative samples from each classification group, by applying the 14C method, and using AMS equipment. And the analysis values were compared with the default values proposed by the IPCC. In this study of garden and park waste and plastics, the differences were within the range of the IPCC default values or the differences were negligible. However, coated paper, synthetic textiles, natural rubber, synthetic rubber, artificial leather, and other wastes showed differences of over 10% in FCF content. IPCC is comprised of largely 9 types of qualitative classifications, in emissions estimation a great difference can occur from the combined characteristics according with the existing IPCC classification system by using the minutely classified waste characteristics as in this study.*

*Implications:* Fossil carbon fraction (FCF) differs depending on the characteristics of waste in each country; and a wide range of default values are proposed by the IPCC. This study conducted research on the existing classifications of the IPCC and Korean waste classification systems based on FCF for accurate greenhouse gas emissions estimation of waste incineration.

## Introduction

Waste management and waste incineration have been discussed as environmental issues for several years (Reinhardt et al., 2007; Merriman, 2008; Pikoń and Gaska, 2010; Ryu, 2012). The incineration method for waste disposal is considered as a main issue in most European countries (Wilson, 2007). Especially, in the case of Switzerland, more than 99% of waste is disposed by incineration (Hügi and Gerber, 2006) Thus, environmental problems and climate change arising from waste incineration are taken quite seriously in Europe (Wilson, 2007).

In Korea, waste disposal methods are largely classified into landfill, incineration, recycling, and so on. As of 2011, the amount of waste buried in landfills decreased by 36.2%, and the amount of incinerated waste rose by 24.5%, compared to the amount in 2002 (Korea Environment Corporation [KECO], 2012). Thus, in the case of Korea, landfill disposal is greatly decreasing, while recycling and incineration have consistently risen. Greenhouse gas emissions from waste incineration was 5,667 Gg $CO_2$eq, which was 39.9% of the total waste emissions in 2010. Since $CO_2$ makes up about 95% of total greenhouse gas emissions from waste incineration, the exact calculation of emissions is necessary (Greenhouse Gas Inventory & Research Center of Korea [GIR], 2012).

In the analysis of $CO_2$ emission estimations of waste incinerators, carbon content, dry substance content, and fossil carbon content by character classification of waste are considered by the Intergovernmental Panel on Climate Change (IPCC). Fossil carbon fraction (FCF) indicates carbon fraction from fossil fuel, and



*Journal of the Air & Waste Management Association*, 65(10):1256–1260, 2015.  ISSN: 1096-2247 print
DOI: 10.1080/10962247.2015.1079563 Submitted February 17, 2015; final version submitted July 3, 2015; accepted July 9, 2015.
Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/uawm.

it is advised that only fossil fuel-based $CO_2$ be calculated in emissions estimations of waste incinerators (IPCC, 2006). Likewise, FCF differs according to the characteristics of waste in each country; default values over a wide range are proposed by the IPCC. The Monitoring and Reporting Regulation (MRR) of the European Union (EU) Emissions Trading System (ETS) states that the $^{14}C$ method or the selective dissolution may be used in order to decide on biomass content. For the analysis of fossil carbon, the $^{14}C$ method, the selective dissolution method, and the balance method are commonly used (Staber et al., 2008; European Commission, 2012).

In Korea, since fossil-fuel-based waste (plastics, vinyl, etc.) and biomass-based waste (food, paper, wood, etc.) are combined and incinerated together, FCF research is much needed, and because character classification of waste differs from the classification system of the IPCC, a precise character classification system is necessary (Kan et al., 2008; Kim et al., 2010). Thus, this study intends to grasp the characteristics of waste for municipal solid waste incinerators and to propose a waste classification system of incinerators by classifying waste characteristics based on fossil carbon content, which most affects $CO_2$ emissions estimations.

# Methods

## Selection of objective facilities and sampling method

In this study, in order to gain a more detailed look into waste characteristics than the classification systems proposed by Korea and IPCC, selected incinerators in Seoul suburbs were visited and a field survey was conducted.

Waste incinerated yearly and the characteristics of municipal solid waste brought in at five incinerators in the suburbs of Seoul were examined through the operation status of the Resource Recovery Facility for municipal solid waste. The amount of municipal solid waste was 133,459 tons at Incinerator A, and 70,241 tons at Incinerator B. The amount of municipal solid waste incinerated was 86,072 tons at Incinerator C, 130,294 tons at Incinerator D, and 84,346 tons at Incinerator E. The characteristics of waste of the five incinerators indicated 31.30–40.53% of paper, 23.92–37.71% of vinyl and plastics, and also included food, textiles, leather, wood, straw, and so on (Table 1).

In order to grasp the characteristics of waste, this survey was conducted by visiting each incinerator more than four times. To understand the waste characteristics, sampling was implemented in accordance with ES 061330 of Waste Management Process Test Standards (Ministry of Environment [MOE], 2011) where waste at depositories was sufficiently mixed with a crane, and approximately 20 kg was collected and then reduced with the conical quartering method.

## Detailed waste sample selection and manufacturing method

In order to manufacture analysis samples of waste, the characteristics of municipal solid waste were gathered by collecting reduced waste, and then they were first classified according to the IPCC standard (Figure 1). Second, additional classification was implemented according to fossil carbon content of the classified waste. The characteristics possible for additional sorting were subclassified according to fossil carbon fraction (FCF) and form. The characteristics sorted according to fossil carbon fraction were paper, textiles, rubber, and leather. Paper was classified into pure paper and processed paper (printed paper, coated paper, etc.); textiles were classified into cotton and synthetic fibers; and rubber and leather were classified into artificial and natural. Also, plastics, to which fossil carbon fraction was interpreted to be similar, but changes in fossil carbon fraction by form were presumed, were classified into vinyl, plastic, Styrofoam, and so on. Thus, analysis samples were manufactured by using waste of the upper 95% by measuring the waste mass ratio of each secondary classification.

## FCF analysis and analysis values comparison

The $^{14}C$ method was applied to measure the fossil carbon content of solid waste. For ASTM D6866, the analysis methods of Liquid Scintillation Counter (LSC), Accelerator Mass Spectrometry (AMS), and Isotope-ratio Mass Spectrometry (IRMS) are proposed (ASTM D6866: ASTM International, 2007; Staber et al., 2008), of which AMS for radiocarbon dating allows analysis with a small sample (below 1 g) and has a 105 times higher degree of precision than general analyzers. Hence, the AMS analysis method was used for the accurate measurement of fossil carbon content (Ruff, 2008). However, many spatial and economic requirements are necessary for AMS analyzers. Since there are only two sets of the required equipment in Korea, analysis was requested from a specialized analysis agency in possession of AMS for measuring the fossil carbon content. Also, for the accuracy of analysis, cross analysis was implemented through a foreign analysis agency with a part of the sample analyzed in Korea, and the mutual analysis values were compared. Lastly, based on the results of fossil carbon content of municipal solid waste of the secondary detailed classification analyzed through this study, the analysis values were compared with the FCF default values proposed by the IPCC.

**Table 1.** The amounts of municipal solid waste, composition, and incineration in plants.

| Division | Incineration (ton/yr) | Paper (%) | Wood, straw (%) | Vinyl, plastic (%) | Food waste (%) | Textiles, leather (%) | Metal, glass (%) | Others (%) |
|---|---|---|---|---|---|---|---|---|
| A | 133,460 | 34.80 | 1.39 | 23.92 | 8.06 | 5.41 | 5.11 | 21.31 |
| B | 70,242 | 40.53 | 12.34 | 26.40 | 7.92 | 6.37 | 6.44 | — |
| C | 86,073 | 31.30 | 3.48 | 27.22 | 10.45 | 17.75 | 9.80 | — |
| D | 130,294 | 33.21 | 8.60 | 37.71 | 10.91 | 4.65 | 6.07 | 4.85 |
| E | 84,347 | 33.48 | 9.62 | 26.45 | 19.27 | 6.65 | 4.53 | — |

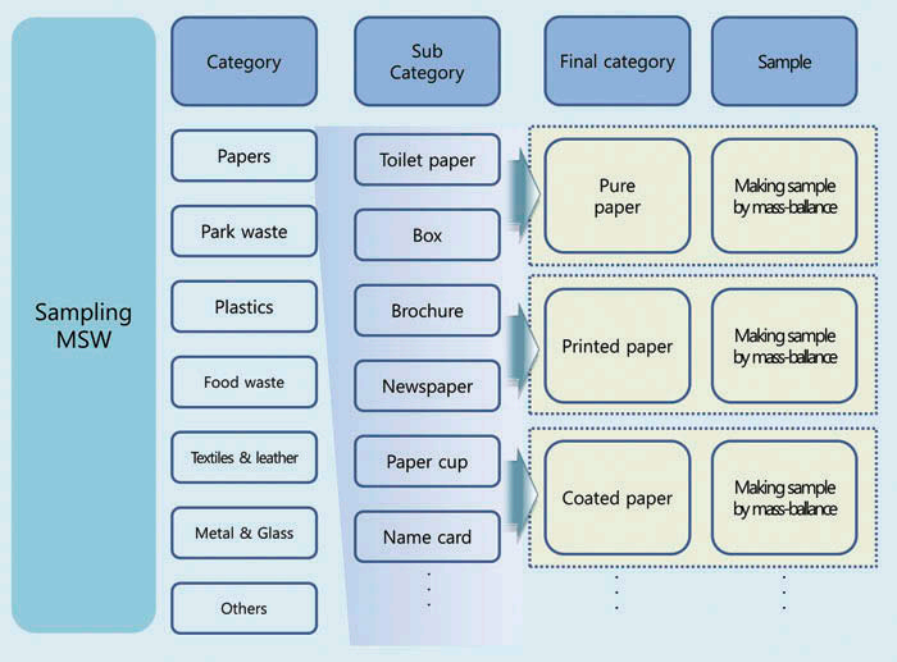


**Figure 1.** Flow chart of municipal solid waste classification and sample production.

# Results

## Survey results of incinerated waste characteristics

The characteristics of municipal solid waste, except for metal, glass, and food, were surveyed according to the IPCC classification system. Classified municipal solid wastes were reclassified into a classification system focused on fossil carbon. In the case of paper, toilet paper, flyers, paper cups, brochures, packing boxes, and newspaper were surveyed, and they were subcategorized into paper, printed paper, and coated paper. In the case of textiles, towels, cotton T-shirts, wet tissue, kitchen paper, and clothes were surveyed, and they were classified into textiles and synthetic textiles. In the case of plastics, plastics, vinyl, food packing materials, noodle and snack bags, Styrofoam, and juice bags were surveyed, and they were subcategorized into plastics, vinyl, and Styrofoam. In the case of wood, wooden chopsticks and toothpicks were surveyed. In the case of garden and park waste, fallen leaves, tree branches, and rice straws were surveyed. For nappies, disposable diapers were surveyed, and there were no characteristics to be classified separately. Rubber and leather were classified into natural and artificial and were subcategorized into natural rubber, artificial rubber, natural leather, and artificial leather. Excluding all of the preceding, all others were classified into soil and characteristics impossible to distinguish with the naked eye (Table 2).

## Analysis results of fossil carbon content

The average results of the FCF analysis by municipal solid waste conducted one to three times through AMS are as shown in Table 3. Fossil carbon fractions were 0–16.2% for paper, 0.7–69.8% for textiles, 0.5% for wood, 1.7% for garden and park waste, 93.3% for nappies, 2.7–96.8% for rubber and leather, 98.3–100% for plastics, and 10.1% for others.

Also, the results of the FCF cross analysis on the identical samples with parts of municipal solid waste conducted by an international agency in possession of AMS, to grasp analysis reliability of the domestic agency, are displayed in Table 4. The results of FCF analysis show that the differences are not great, within about 1%: 0.7% in the case of cotton textiles, 0.5% for natural leather, 0.3% for synthetic rubber, and 1.3% for artificial leather. Although differences under 10% occurred in the case of coated paper (5.5%), synthetic textiles (10.3%), disposable diapers (4.6%), natural leather (4.9%), and others (3.3%), analysis results of the domestic agency were considered to be reliable due to the low level of difference between the analyses.

## Comparison of fossil carbon contents

For the comparison of fossil carbon contents, the weighted average values were calculated for the FCF results estimated in this study, and the domestic default values are shown in Table 5. Paper was 3.9%, and although the IPCC's results were similar at 0–5%, the differences were significant depending on printing and coating degrees of paper. In the case of textiles, the difference was great between cotton and synthetic textiles; the range of the IPCC was wide at 0–50%. In the case of rubber and leather, natural leather was generally low, and synthetic and artificial materials were generally high. In the case of nappies in this study, it was 93.3 %, but the IPCC results showed a wide difference at 10%. This is owing to the fact that in the case of foreign countries, nappies have almost no fossil carbon content because they are made with cotton materials. In the case of wood, garden, and park waste and plastics, both the IPCC and this study show similar numerical

**Table 2.** The result of fossil carbon category in this study.

| IPCC category | MSW characteristics | FCF category in this study |
|---|---|---|
| Paper | Toilet paper, box, etc. | Paper |
| | Newspaper, paper bag, book, A4 paper, receipt, paper packing, scratch paper, etc. | Printed paper |
| | Brochure, paper cup, milk carton, name card, cigarette case, etc. | Coated paper |
| Textiles | Towel, cotton, underwear, gloves, socks, cotton wool, etc. | Textiles |
| | Wet wipes, kitchen towel, clothes, dishcloth, banner, ribbon, sponge, etc. | Synthetic textiles |
| Plastics | Plastic (Polypropylene, other, Polystyrene, Polyethylene terephthalate), toothpaste, straw, card, onion net, plastic spoon, button, etc. | Plastic |
| | Vinyl (Low-density polyethylene, Polypropylene, High-density polyethylene), plastic bag, food packing, noodle bag, snack bag, sanitary gloves, juice bag, zipper bag, wet wipes case, plastic string, plastic wrap, latex glove, etc. | Vinyl |
| | Styrofoam, etc. | Styrofoam |
| Wood | Wooden chopsticks, toothpick, etc. | Manufactured timber |
| Garden and park waste | Leaves, branches, straw, etc. | Garden and park waste |
| Nappies | Disposable diapers, etc. | Disposable diapers |
| Rubber and leather | Natural rubber gloves, etc. | Natural rubber |
| | Synthetic rubber gloves, etc. | Synthetic rubber |
| | Natural leather clothes, etc. | Natural leather |
| | Synthetic leather clothes, etc. | Synthetic leather |
| Others | Ash, dirt, dust, soil, etc. | Others |

**Table 3.** The result of fossil carbon fraction based on this study category.

| IPCC category | FCF category in this study | FCF average (%) |
|---|---|---|
| Paper | Paper | 0 |
| | Printed paper | 3.7 |
| | Coated paper | 16.2 |
| Textiles | Textiles | 0.7 |
| | Synthetic textiles | 69.8 |
| Wood | Manufactured timber | 0.5 |
| Garden and park waste | | 1.7 |
| Nappies | Disposable diapers | 93.3 |
| Rubber and leather | Natural rubber | 2.7 |
| | Synthetic rubber | 96.8 |
| | Natural leather | 39.2 |
| | Synthetic leather | 70.1 |
| Plastics | Vinyl | 99.2 |
| | Plastic | 100 |
| | Styrofoam | 98.3 |
| | Others | 10.1 |

values. In the case of others, municipal solid waste was classified by its characteristics and was classified only into the solid waste of small particles indistinguishable with the naked eye. Also, their fossil carbon content is presumed to be low, since most of them contain a great deal of inorganic soil particles.

## Conclusion

This study conducted research on the existing classifications of the IPCC and Korean waste classification systems based on FCF for accurate greenhouse gas emissions estimation of waste incineration. In waste classification, additional classifications were implemented depending on whether waste contained fossil carbon in the existing IPCC classification system. The characteristics possible for additional sorting, according to fossil carbon fraction and form, were subclassified. The analysis of FCF was implemented by collecting representative samples from each classification group by applying the $^{14}C$ method and using AMS equipment. The analysis values were compared with the default values proposed by the IPCC.

**Table 4.** Comparison of fossil carbon fraction analysis result by cross validation.

| Category | A analysis institution | B analysis institution | Deviation |
|---|---|---|---|
| Coated paper | 16.2 ± 3 | 21.7 ± 3 | 5.5 |
| Textiles | 0.7 ± 3 | 0 ± 3 | 0.7 |
| Synthetic textiles | 69.8 ± 3 | 80.1 ± 3 | 10.3 |
| Disposable diapers | 93.3 ± 3 | 97.9 ± 3 | 4.6 |
| Natural rubber | 2.7 ± 3 | 2.2 ± 3 | 0.5 |
| Synthetic rubber | 96.8 ± 3 | 97.1 ± 3 | 0.3 |
| Natural leather | 39.2 ± 3 | 34.3 ± 3 | 4.9 |
| Synthetic leather | 70.1 ± 3 | 68.8 ± 3 | 1.3 |
| Others | 10.1 ± 3 | 6.8 ± 3 | 3.3 |

As the result of the comparison, the differences were 2.9% for paper, 10.3% for textiles, 1.7% for garden and park waste, 83.3% for nappies, 32.2% for rubber and leather, 0.1% for plastics, and 89.9% for others. In the case of garden and park waste and plastics, the differences were either within the range of the IPCC default values or negligible. However, coated paper,

**Table 5.** Comparison of fossil carbon fraction in this study.

| Category | FCF category in this study | FCF (%) This study | FCF (%) IPCC default |
|---|---|---|---|
| Paper | Paper<br>Printed paper<br>Coated paper | 3.9 | 1 (0–5) |
| Textiles | Textiles<br>Synthetic textiles | 30.3 | 20 (0–50) |
| Wood | Manufactured timber | 0.5 | — |
| Garden and park waste | | 1.7 | 0 |
| Nappies | Disposable diapers | 93.3 | 10 |
| Rubber and leather | Natural rubber<br>Synthetic rubber<br>Natural leather<br>Synthetic leather | 52.2 | 20 |
| Plastics | Vinyl<br>Plastic<br>Styrofoam | 99.9 | 100 (95–100) |
| Others | | 10.1 | 100 (50–100) |

synthetic textiles, natural rubber, synthetic rubber, artificial leather, and other wastes showed differences of over 10% in FCF content.

Likewise, most characteristics were estimated in a similar manner, but some of the characteristics showed relatively wide differences. It is presumed that the differences occurred because the judgment standards for waste characteristics (biomass materials) are different according to agency and necessity, despite having identical characteristics, and because of the differences in waste characteristics by country. Even though the classification system for incinerated waste of IPCC is comprised of largely nine types of qualitative classifications, a great difference can occur in emissions estimation from the combined characteristics according to the existing IPCC classification system by using the minutely classified waste characteristics as in this study.

Thus, to build accurate greenhouse gas inventories, further studies on the classification system focused on FCF content of the existing IPCC classification system and FCF studies by waste should be consistently conducted. By consistently implementing such studies, national greenhouse gas inventories for waste incineration can be improved.

## Funding

This work is financially supported by the Korea Ministry of Environment (MOE) as Graduate School specialized in Climate Change.

## References

ASTM International. 2007. ASTM D6866–08. Standard Test methods for determining the biobased content of solid, liquid, and gaseous samples using radiocarbon analysis. http://www.astm.org/DATABASE.CART/HISTORICAL/D6866-08.htm

European Commission. 2012. Biomass issues in the EU ETS MRR Guidance document No. 3. Final version of 17. http://ec.europa.eu/clima/policies/ets/monitoring/docs/gd3_biomass_issues_en.pdf

Greenhouse Gas Inventory & Research Center of Korea. 2012. National inventory report 2012.

Hügi, M., and P. Gerber. 2006. Abfallstatistik 2004. Federal Office for the Environment. 104.

Intergovernmental Panel on Climate Change. 2006. 2006 IPCC guidelines for national greenhouse gas inventories. https://www.ipcc.ch/meetings/session25/doc4a4b/vol5.pdf

Kan, S. Y., J. H. Hong, S. B. Lee, and Y. J. Han. 2008. Estimation and projection of greenhouse gas emissions from waste incinerators in Korea. *Journal J. Korean Soc. Environ. Eng*. 30(3):250–56.

Kim, B.-S., S.-D. Kim, C.-H. Kim, and T.-J. Lee. 2010. Property analysis of municipal solid waste and estimation of $CO_2$ emissions from waste incinerators. *J. Korean Soc. Atmos. Environ*. 26(6):657–65. doi:10.5572/KOSAE.2010.26.6.657

Korea Environment Corporation. 2012. Generation and current treatment status of waste in Korea 2011. http://library.nier.go.kr/viewer/MediaViewer.ax?cid=5527831&rid=28&moi=258250

Merriman, J.A. 2008. Waste management and global warming: Finding the least greenhouse gas pathways. *J. Air Waste Manage. Assoc*. 6(3):213–27. doi:10.1080/08941929309380822

Ministry of Environment. 2011. Waste management process test standards. http://www.me.go.kr/home/file/readDownloadFile.do;jsessionid=5KDUdcS68T1KDwo6OtTB2r4QjvXxH5CIOFOOWPJ8CPcFyFeLSGv7OZp2clD1XKbe.meweb2vhost_servlet_engine1?fileId=97602&fileSeq=1

Pikón, K., and K. Gaska. 2010. Greenhouse gas emission mitigation relevant to changes in municipal solid waste management system. *J. Air Waste Manage. Assoc*. 60(7):782–88. doi:10.3155/1047-3289.60.7.782

Reinhart, T., U. Richers, and H. Suchomel. 2007. Hazardous waste incineration in context with carbon dioxide. *Waste Manage. Res*. 26:88–95. doi:10.1177/0734242X07082339

Ruff, M. 2008. Radiocarbon measurement of micro-scale samples—A carbon dioxide inlet system for AMS. Philosophisch-naturwissenschaftlichen Fakultät der Universität Bern, Bern, Switzerland.

Ryu, C. 2012. Potential of municipal solid waste for renewable energy production and reduction of greenhouse gas emissions in South Korea. *J. Air Waste Manage. Assoc*. 60(2):176–83. doi:10.3155/1047-3289.60.2.176

Staber, W., S. Flamme, and J. Feltner. 2008. Methods for determining the biomass content of waste. *Waste Manage. Res*. 26:78–87. doi:10.1177/0734242X07087313

Wilson, D.C. 2007. Development drivers for waste management. *Waste Manage. Res*. 25:198–207. doi:10.1177/0734242X07079149

## About the Authors

**Jeongwoo Lee** is a researcher in the Department of Earth and Environmental Sciences at Sejong University.

**Seongmin Kang** is a researcher and **Eui-Chan Jeon** is a professor in the Department of Environment & Energy at Sejong University.

**Seungjin Kim** is a researcher at the Cooperate Course for Climate Change at the Sejong University.

**Ki-Hyun Kim** is a professor in the Department of Civil & Environmental Engineering at Hanyang University.