미세먼지와 기후변화 동시 대응을 위한
통합 정책방안 마련 연구

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<훈련결과보고서 요약서>

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훈 련 국	미 국	훈련기간	2020.8.13. - 2022.6.12.
훈련기관	콜로라도 대학교 (University of Colorado Denver)	보고서 매수	101 매
훈련과제	미세먼지와 기후변화 동시 대응을 위한 통합 정책방안 마련 연구		
보고서 제목	A study on the preparation of integrated policy measures to simultaneously respond to fine dust and climate change in Korea		
내용요약	Ⅰ. 서론 콜로라도 대학교(University of Colorado Denver)에서 2년간('20.8-'22.6) 수학한 행정학을 바탕으로, 훈련과제인 "미세먼지와 기후변화 동시 대응을 위한 통합 정책방안"을 고찰하려 한다. 오염 배출원이 유사하고 저감 방안도 유사한 미세먼지와 온실가스를 효과적으로 관리하기 위한 방안을 제안하기 위해, 공동이익(co-benefit) 관점에서 도시의 특성들을 중심으로 연관성을 분석하였다. 또한, 분석결과를 바탕으로, 미세먼지 등 대기오염물질과 기후변화를 유발하는 온실가스를 함께 저감하기 위한 정책들을 제시하였다. Ⅱ. 본론 1. 목적		

기후 변화는 세계 모든 지역에서 폭염, 폭우, 가뭄, 열대성 저기압과 같은 기상 및 극한 기후에 영향을 미치고 있으며 기후 시스템의 여러 측면에서 최근 변화의 규모는 수세기 동안 전례가 없다. 또한 향후 수십 년 동안 전 세계 CO_2 및 기타 온실가스 배출량이 크게 감소하지 않는 한 2021년에서 2040년 사이의 지구 평균 기온은 산업화 이전 시대에 비해 섭씨 1.5도 증가할 가능성이 있다(IPCC, 2021). 한국도 기후변화의 영향에서 자유롭지 못하다. 최근 우리나라는 기후변화로 인한 극심한 고온, 국지적 집중호우, 온난한 겨울을 겪고 있으며 이는 사회적, 경제적 비용뿐만 아니라 국민의 건강에도 영향을 미치고 있다.

지구적 차원의 기후변화와 지역적 차원의 대기오염 문제는 별도로 연구되고 있지만, 화석연료 연소 시 동시에 배출되는 온실가스와 대기오염물질은 밀접한 관련이 있다. 2006년 IPCC 국가 온실가스 인벤토리 가이드라인에서는 일산화탄소(CO), 이산화질소(NO_2), 이산화황(SO_2) 등을 간접온실가스로 규정하고 있는바, 두 문제에 동시에 영향을 주는 물질을 우선적으로 줄이는 것이 효과적인 문제해결에 도움이 될 것이다.

2. 연구내용

본 연구는 기후변화와 미세먼지 등 대기오염을 동시에 줄일 수 있는 다양한 방법 중 도시에서 발생하는 물질을 분석하기 위해 수행되었다. 본 연구에서는 기후변화와 대기오염을 동시에 저감하기 위한 합리적인 대책을 도출한다는 목표를 고려하여 객관적 근거와 함께 도시 부문의 특성을 심도 있게 분석하였다, 온실가스 및 대기오염물질의 주요 발생원은 전 지역에 걸쳐 존재하지만, 본 연구에서는 인구밀도, 교통, 산업 등 현대인의 활동과 밀접한 도시의 특성을 분석하여 정책적 시사점을 도출하는 데 중점을 두었다.

본 연구의 연구질문(research question)은 다음과 같다. 도시의 어떤 요소들이 기후변화와 대기오염을 동시에 유발하는 NO_2, CO, SO_2, PM_{10}, $PM_{2.5}$의 대기 중 농도와 밀접한 관련이 있는가. NO_2, CO, SO_2는 기후변화와 대기오염을 동시에 가속시키는 물질이며, PM_{10}과 $PM_{2.5}$는 현재 우리나라에서 가장 중요한 대

기오염물질이기 때문이다. 따라서 이러한 물질과 도시의 특성을 특정 수준에서 분석하여 관련성과 경향성을 파악할 수 있다면 이러한 물질의 발생을 억제할 수 있고 향후 도시계획에 의미 있는 정책적 시사점을 제공할 수 있다. 따라서, 이 연구의 범위는 대기오염 현황에 대한 자료를 확보할 수 있는 도시 대기 측정망을 갖춘 대도시와 중도시를 대상으로 한다. 본 연구는 객관적으로 측정 가능한 자료를 바탕으로 정확한 사실관계를 규명해야 하므로 공인된 측정망을 구축한 도시에서 확보한 자료만을 사용하였다.

본 연구에서는 대기 오염 물질별로 배출량과 대기 오염 상태를 기준으로 도시를 분류한 후, 도시 특성 변수를 독립변수로, 대기 오염 물질을 종속변수로 설정하여 상관관계를 분석하였으며, 회귀분석을 통해 변수 간 관계를 파악한 후 기후변화와 대기오염을 동시에 유발하는 물질을 줄이는 정책적 시사점을 제시하였다.

3. 한국의 현황

① 이산화황(SO_2)

이산화황은 물에 쉽게 용해되는 무색의 자극성 난연성 물질로, 유황을 함유한 연료인 석탄과 석유의 연소, 금속 제련 및 기타 산업 공정에서 발생한다. 한국의 경우, 연간 평균 오염 수준이 감소하고 있다. 2002년부터 2009년까지는 변화가 없었지만, 2010년 연평균은 0.005ppm으로 전년도에 비해 0.001ppm 감소하였다. 2019년부터 현재까지 SO2 농도는 0.004ppm으로, 0.001ppm 더 낮춘 수준을 유지하고 있다.

② 일산화탄소 (CO)

일산화탄소는 탄소 성분이 불완전 연소될 때 발생하는 무색, 무취의 유독 가스이다. 연소 중 산소가 부족하거나 연소 온도가 낮으면 완전 연소가 되지 않아 불완전 연소 생성물인 일산화탄소가 발생한다. 한국의 경우, 과거 연탄 사용이 많아 난방 연료가 일산화탄소의 주요 배출원이었으나, 1990년대 연료전환 정책과 자동차 대수가 급격히 증가함에 따라 현재는 자동차에서 배출되는 일산화탄소가 주요 배출원이다. 1999년부터 2002년까지 1.0ppm에서 0.7ppm으로 크게 감소한 이후, 점차 오염도가 낮아

져 2009년부터 현재까지 0.5ppm으로 일정하게 유지되고 있다

③ 이산화질소 (NO_2)

이산화질소는 적갈색의 반응성이 높은 기체이며 대기 중 일산화질소의 산화에 의해 생성된다. 한국의 경우, 1998년부터 2001년까지 매년 조금씩 악화되었으나, 2002년부터 2010년까지는 큰 변화 없이 일정한 수준을 유지하였다. 그러나 2011년부터 2014년까지 소폭 증가와 감소를 반복하였고, 2015년부터는 감소하는 경향을 보이며, 0.018ppm(2019)까지 감소하였다.

④ 미세먼지 (PM_{10}, $PM_{2.5}$)

미세먼지는 공기 중의 고체와 분무 입자의 혼합물인데, 배출원에서 직접 배출되거나 이산화황, 질소산화물(NOx) 등 기체상 물질에 의해 2차적으로 발생한다. 미세먼지의 크기와 구성은 매우 복잡하고 다양하며 입자의 크기, 표면적, 화학적 조성이 건강에 미치는 영향을 결정하는 것으로 알려져 있다. PM_{10}의 경우 1995년 측정 이후 점차 감소하고 있다. 대기 중 농도는 1998년 55㎍/㎥에서 2007년 58㎍/㎥로 증감을 반복하다가 2008년 54㎍/㎥로 크게 감소했다. 2012년에는 45㎍/㎥로 매우 낮은 수준었으나, 그 후 소폭 증가하다가 2019년에는 41㎍/㎥로 낮은 수준을 유지했다, $PM_{2.5}$의 경우, 오염도의 공식 기록이 2015년부터 시작되었는데, 2015년의 대기 농도는 26㎍/㎥이었으나 점차 감소하여 2017년 25㎍/㎥, 2018년과 2019년에는 23㎍/㎥을 기록했다.

⑤ 온실가스

한국의 2018년 총 온실가스 배출량(LULUCF 제외)은 7억 2,760만톤으로 1990년 총배출량 2억 9,220만톤 대비 149.0%, 2017년 총배출량 7억 9,70만톤 대비 2.5% 증가했다. 2018년 온실가스 순배출량(LULUCF 포함)은 6억 8,630만톤으로 1990년 2억 5,440만톤보다 169.8% 증가했으며 2017년 6억 6,830만톤보다 2.7% 증가했다.

4. 문헌검토

문헌 검토 결과는 다음과 같이 요약된다. 첫째, 도시의 특성은 대기오염과 밀접한 관련이 있다. 도시 구성, 인구 밀도, 인구 분산, 인간 활동과 같은 도시 요소는 대기 오염 물질을 생성하거나 악화/완화시켜 도시의 대기 질에 영향을 미친다. 둘째, 교통과 인구밀도와 같은 요소들이 대기오염물질의 발생에 직접적인 영향을 미친다. 교통량의 증가와 인구의 집중은 대기 오염을 악화시킬 수 있고, 두 가지 요인이 결합하여 공기를 더 나쁘게 만들 수 있다. 논문은 이를 바탕으로 자전거·보행 등 친환경 교통수단 확충과 도시 간 연계성 강화 등의 정책을 제시하고 있다.

5. 연구방법

본 연구에서는 얼마나 많은 도시 특성들이 대기오염 및 기후변화와 밀접하게 관련되는지 분석하고, 이러한 결과를 바탕으로 대기질 개선 및 기후변화 대응을 위한 정책적 시사점을 제시하고자 한다. 이를 위해 도시의 특성과 대상 물질들 간의 상관분석과 다중회귀분석을 실시하여 유의한 수준에서 상관관계를 도출한다.

① 연구질문 (research question)

기후변화 및 대기오염을 유발하는 대기 중의 NO_2, CO, SO_2, PM_{10}, $PM_{2.5}$ 의 대기 중 농도와 도시의 어떤 요소가 밀접한 관련이 있는가?

② 연구가설 (hypothesis)

인구밀도, 자동차밀도, 도로밀도, 산업은 NO_2, CO, SO_2, PM_{10}, $PM_{2.5}$ 의 대기 중 농도와 양의 상관관계가 있다.

③ 변수 (variables)

도시 특성 변수가 대기오염 및 기후변화를 유발하는 물질들의 농도에 어떤 영향을 미치는지 파악하는 것이 본 연구의 목적이므로, 도시에서 발생하는 NO_2, CO, SO_2, PM_{10}, $PM_{2.5}$ 의 대기 중 농도를 종속변수로 설정하였다. 또한, 독립변수로는 상관분석에 필요한 도시 구성 요소로 인구통계학적 특성, 교통특성, 토지특성, 산업특성으로 설정하였는데, 구체적인 항목들은 다음과

같다.

1) 인구통계학적 요인: 인구수, 인구밀도

2) 교통요인: 자동차 밀도, 도로 밀도

3) 토지이용요인: 녹지 밀도, 토지 밀도

4) 산업적 요인: 식품 및 음료 제조엄체 밀도, 섬유, 의류, 피혁 제조사의 밀도, 목재, 가구, 종이 제조사의 밀도, 석유화학 업체 밀도, 제강 및 금속가공업체의 밀도, 자동차 및 운송장비 제조사의 밀도, 전기, 전자, 기계 제조사의 밀도, 의료 물질 및 의약품 제조업체의 밀도, 인쇄매체 및 기록매체 제조사의 밀도, 고무 및 플라스틱 제조사의 밀도

인구특성 중 인구 밀도는 대기오염의 원인으로서 매우 중요한 역할을 하기 때문에 매우 중요한 변수이다. 따라서 인구 밀도와 인구수를 분석하여 상관 관계가 있는지 여부를 판단한다.

문헌고찰에서 알 수 있듯이 교통특성은 대기오염에 직접적인 영향을 미치는 중요한 변수이다. 그러나 차량 등록 대수가 도로의 실제 교통을 나타내지는 않으므로, 교통 특성을 자동차 밀도와 도로 밀도로 구분하여 분석한다.

녹지, 농업 등 용도별로 사용되는 토지에 따라 연구 대상 오염 물질이 얼마나 배출되는지 평가하기 위해 용도별 토지 인구 대비 토지 특성을 분석한다.

마지막으로 대기오염과 기후변화에 대한 기여도가 가장 높은 부문 중 하나인 산업의 특성을 구분하여 독립변수로 설정하였다. 이것은 한국도시통계(2020)의 산업분류에 따라 재분류하였으며, 도시면적을 이용한 밀도를 독립변수로 설정하였다.

6. 데이터 수집 및 분석

① 데이터 수집

종속변수인 도시별 대기오염 측정자료는 국립환경과학원의 최신 대기환경연보(2019)를 사용하였다. 대기오염물질별 배출자료는 국립환경과학원에서 발간하는 국가 대기오염물질 배출량(2020)을 사용하였다. 또한, 독립변수인 도시특성은 행정안전부 고시 한국도시통계(2020)에 근거하여 분석 목적에 따라 재가공하여 사용하였다.

본 연구에서는 분석할 도시를 선정하기 위해 표본추출을 수행하였다. 현재, 한국의 도시 대기 모니터링 네트워크는 161개 도시에 495개의 측정소를 설치하고 운영 중이다. 분석 대상 도시에는 이러한 감시소가 건설되고 운영되어야 하며, 대기오염이 인간활동에 밀접한 영향을 미친다는 점을 토대로 인구 20만명 이상 52개 도시를 분석하였다.

② 데이터 분석

데이터를 분석하고 가설을 검정하는 데 SPSS 프로그램을 사용하였다. 먼저 도시특성변수와 대기오염물질의 상관관계를 밝히기 위해 피어슨 상관분석을 실시했고, 이 분석의 통계적 유의성을 확인하기 위해 양측 검정을 수행하였다. 또한, 선형 회귀분석을 이용하여 독립변수로서의 도시특성과 종속변수로서 오염물질들에 의한 대기오염과의 인과관계를 추론하였다. 회귀 분석의 유의성은 F-값과 분산 분석의 유의성 확률로 검증하고 공차 및 VIF(Variance Inflation Factor)를 검토하여 다중 공선성 문제를 확인했다. 이를 통해 대기오염에 밀접한 영향을 미치는 도시특성을 부문별로 파악할 수 있으며, 이러한 특성을 분석해 대기질 개선 및 기후변화 대응을 위한 정책들을 제안했다.

③ 방법론의 한계

대기오염은 다양한 요인, 특히 바람과 기온 등 기후요인이 복합적으로 발생하는 현상이기 때문에 도시 특성과 직접적인 상관관계를 분석하기 어렵다. 다만 도시에서 발생하는 대기오염 물질 등의 발생량을 종속변수로 설정하기보다는 대기 중 오염 농도의 측정값을 종속변수로 설정하여, 기후요인이 이미 포함되어 있다고 가정하고 분석을 진행하였다.

7. 결과

7.1. 상관관계 분석

① 이산화황(SO_2)

독립변수 중 산업적 요인과 강한 상관관계가 형성되었다. 철강 및 금속 가공 제조업체의 밀도($r(52) = .203$, $p<.01$), 석유

화학 제조업체의 밀도(r(52) = .408, p<.01), 전자, 전기, 기계 제조업체의 밀도(r(52) = .407, p<.01) 및 고무 및 플라스틱 제조업체의 밀도(r=01)가 높은 상관관계를 보였다.

② 일산화탄소 (CO)

농지용 토지(r(52) = 0.356, p<.01)가 가장 높은 양의 상관관계를 보였고, 의약품 제조업체의 밀도(r(52) = 0.334), p<.01), 자동차 밀도(r(52) =.300, p<.01)가 높은 상관관계를 보였지만, 전반적으로 도시 특성들과 낮은 상관관계를 나타냈다.

③ 이산화질소 (NO_2)

독립 변수의 모든 범주와 밀접하게 상관관계가 나타났다. 자동차 밀도(r(52) = 0.657)와 가장 높은 양의 상관관계를 보이며, 이어서 인구밀도(r(52) =.647, p<.01), 의약품 제조업체 밀도(r(52) = 0.555, p<.01), 농업용 토지(r(52) = -.195, p<.01), 전자, 전기, 기계 제조업체 밀도(r=451, p<52)의 상관관계가 높았다.

④ 미세먼지 (PM_{10})

PM_{10}의 도시 특성과의 상관관계 분석 결과, 녹지(r(52) = -.573, p<.01), 고무 및 플라스틱 제조업체 밀도(r(52)) = .402, p<.01), 의약품 및 의약품 제조업체 밀도(r(52) = .360, p<.01)는 높은 양의 상관관계가 있는 것으로 나타났다.

⑤ 미세먼지 ($PM_{2.5}$)

PM2.5의 경우 전반적으로 도시특성과의 관계가 가깝지 않은 것으로 나타났다. 인구수(r(52) = .306, p<.01)와 녹지(r(52) = -.303, p<.01)가 높은 상관관계를 나타내는 것으로 분석되었다. 그러나 본 연구에서 PM_{10}과 $PM_{2.5}$에 관해서는 녹지가 높은 상관관계를 갖는 중요한 요인으로 분석되었다.

7.2. 회귀 분석

본 연구에서는 대상 물질들과 도시특성 변수의 상관관계 분석 결과를 바탕으로, 상관관계가 높고 통계적으로 유의한 변수

에 대한 회귀분석을 수행하였다. CO, SO_2, $PM_{2.5}$에 대한 회귀 분석 결과는 설명력이 거의 없었으나 NO_2, PM_{10}에 대한 분석 결과는 다음과 같다.

① 이산화질소 (NO_2)

NO_2와 도시특성 변수 사이의 회귀모형을 추정한 결과, F-값은 7.565(p<.001)로 통계적으로 유의하였다. 추정된 회귀분석 모형의 설명력을 의미하는 결정계수는 0.669로 설명력이 66.9%임을 의미한다. NO_2 농도에 큰 영향을 미치는 변수로 도로밀도(t=-4.384, p<.01), 고무 및 플라스틱 제조업체의 밀도(t=-2.403, p<.05) 및 농경지의 밀도(t=-1.752, p<.1)로 나타났다. 변수의 영향을 나타내는 표준화된 계수를 바탕으로 3가지 독립변수 중 도로밀도(θ=-1.1.19), 고무 및 플라스틱 제조업체의 밀도(θ=-0.568) 및 농경지의 밀도(θ=-0.249)가 NO_2 농도에 영향을 미치는 것으로 분석되었다.

② 미세먼지 (PM_{10})

PM_{10} 회귀 분석 모델에서 F-값은 통계적으로 유의한 3.313이었고(p=.001), 결정 계수는 41.6%의 설명력을 갖는 0.416이었다. PM_{10} 농도에 큰 영향을 미치는 변수로는 인구수(t=-1.725, p=.093)과 녹지 밀도(t=-3.195, p=.003)로 나타났다. 이 가운데 녹지 밀도(μ=-0.671)와 인구수(μ=-0.380)가 PM_{10} 농도에 영향을 미치는 것으로 분석됐다.

8. 정책제안

① 일반 제안

첫째, 교통분야에서 발생하는 대상 물질을 효과적으로 줄일 필요가 있다. 이를 위해 노후화되어 오염물질을 많이 배출하는 경유 차량을 줄여야 한다. 이들 차량을 조기 폐차할 경우 저공해 차량 구입 지원 보조금을 늘려 교통분야의 오염원을 획기적으로 줄일 필요가 있다.

둘째, 본 연구에서 수행한 상관관계 분석에 따르면 대상 물질들은 석유화학 제조, 제철, 의약품 제조 등 다양한 산업과 높은 상관관계를 보였다. 산업 분야에서 배출되는 대상 물질들을

줄이기 위해서는 배출가스 기준규정을 강화해야 하고, 이를 어기는 행위도 엄정하게 시행해 처벌해야 한다.

셋째, 대상 물질들과 부정적 상관관계가 있는 녹지 및 농업용 토지를 활용하는 정책이 검토돼야 한다. 그동안 국내 대기질 관리 정책은 대기오염물질 배출 감소에 초점을 맞춰 왔지만 산림과 경작지를 유지하거나 확대하는 정책 추진도 고려되어야 한다. 특히 미세먼지의 경우 발생 원인과 조건이 복잡해 저감하기 어려운데, 도시농업과 옥상녹화 등 도심 녹지·경작지 확대 방안을 도입할 필요가 있다.

② 부문별 정책 제안

첫째, 산업 부문에는 여전히 불법적으로 대기오염물질을 배출하는 산업이 있어 강력한 규제가 필요하다. 우선 사업장 내 오염물질 불법 배출에 대한 모니터링을 강화하여 배출 조작 등 불법행위를 강력하게 제제할 필요가 있다. 또한 드론이나 과학장비를 활용하여 단속의 효율성을 높이고 신고포상제도를 확대해 단속의 실효성을 높일 필요가 있다. 또한 오염물질 관리능력이 낮은 중소기업을 위한 기술과 자금조달도 병행하여, 배출시설을 적절하게 운영할 수 있는 기술을 습득할 수 있도록 지원을 대폭 확대해야 한다.

둘째, 대기오염 물질 중 CO, NOx, 미세먼지의 상당수가 자동차에서 배출된다. 현재 강화된 배출기준 및 차량배출 등급제를 시행하고 있으며, 미세먼지 긴급저감조치 시 배출가스 5등급 차량에 대한 운행제한 조치가 시행되고 있으나, 노후 경유차량 조기폐차 유도, 매연저감장치 설치 등 대기오염 및 미세먼지 저감 대책을 지속적으로 추진하는 동시에, 전기차, 수소차 등 저공해자동차 보급을 더욱 확대하고 다양한 정책을 조화롭게 추진하여 친환경 교통체계를 구축해야 한다.

셋째, 오염원 통제와 배출량 감축 뿐만 아니라 산림·경작지 확대 정책도 검토할 필요가 있다. 과도한 도시화는 다양한 인간의 활동과 도시 특성으로 인해 불리한 환경 조건을 악화시킨다. 오염원으로서의 도시가 아니라 녹지공간을 확보해 대기오염과 기후변화를 함께 완화할 수 있는 조화로운 방법의 도입이 필요하다.

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3. 훈련분야 : 행정학

4. 훈련기간 : 2020.8.13. - 2022.6.12.

훈련기관개요

□ 콜로라도 대학 (University of Colorado)의 역사

○ 콜로라도 대학은 1883년 9월에 볼더(Boulder) 캠퍼스에 의학 및 외과의학과를 신설하며 개교

○ 최근(2014), 콜로라도 대학교는 콜로라도 덴버 대학(University of Colorado Denver)과 콜로라도 안슈츠 의과대학(University of Colorado Anschutz Medical Campus)에 별도의 총장을 임명하여 두 캠퍼스를 분리

* 양 캠퍼스는 일부 공동 프로그램을 운영하지만 별도의 기관이며, 공식적으로도 CU Anschutz, CU Denver로 독립적인 호칭을 사용

□ 콜로라도 덴버 대학 (University of Colorado Denver)의 역사

○ 1912년에 창립하여 1973년부터 독립적으로 운영

- 1912년 볼더에 있는 콜로라도 대학교는 덴버로 확장했고, 1971년에 현재의 문과대학을 설립

- 1973년 콜로라도 주의회는 주 헌법을 수정하여 콜로라도 덴버 대학을 설립

- 포용의 문화(Culture of Inclusion)가 번성할 수 있는, 존중하는 학습 문화 조성을 위해 노력

○ 콜로라도 대학은 공식적으로 콜로라도 주(state)에서 1위, 미국 전역에서는 소셜 모빌리티 분야 55위를 기록 (2022)

□ 콜로라도 덴버 대학 캠퍼스 및 커뮤니티

○ 덴버 시내에 위치한 대학교는 티볼리 학생회(Tivoli Student Union) 및 오라리아 도서관(Auraria Library)을 포함

○ 시티센터(City Center)는 시민, 비영리단체 및 사업 리더에게 대학의 자원들을 제공하며, 캠퍼스와 지역 커뮤니티를 연결

* 1,000명이상의 교수진과 전문가가 연결되어 있고, 도시문제를 해결하는 등 지역사회를 지원하는 30개 이상의 프로젝트를 완료

○ 10만명 이상의 동문을 배출하고 1,138명의 교수진을 구성하며, 콜로라도 경제에 8억 2백만 달러의 경제적 영향을 미침

□ 콜로라도 덴버 대학교 행정학과 (School of Public Affairs)

○ (목적) 공공서비스 리더쉽과 공공 및 비영리 기관에서의 경력을 쌓기 위한 학생들을 위한 교육 프로그램을 제공

- 인턴쉽, 연구 및 지역 비영리 단체 및 정부 기관과의 협업 기회가 많으며 경력을 관리할 수 있는 최상의 기회를 제공

* 미국 노동 통계국에 따르면 전체 일자리의 25%가 정부 또는 비영리 부문이 존재하므로, SPA에서의 경력이 이러한 분야와 높게 연결

○ (사명) 사회의 가장 시급한 문제를 해결하기 위해 공공 서비스 및 형사 사법 분야의 차세대 지도자를 양성

- 주(State) 및 국가(Nation)의 정책을 입안할 수 있는, 더 나은 미래에 대한 비전을 가진 학생들을 양성

○ 콜로라도 주(State) 내 행정학과 순위 1위 및 미 전역 29위

* U.S. News & World Report 2023 Best Graduate Schools Rankings
#1 in Environmental Policy and Management in Colorado (#10 in the nation)
#1 in Nonprofit Management in Colorado (#16 in the nation)
#1 in Public Finance and Budgeting in Colorado (#19 in the nation)
#1 in Public Management and Leadership in Colorado (#21 in the nation)
#1 in Local Government in Colorado (#25 in the nation)

Chapter 1. Introduction

1.1 Project Purpose

Climate change is affecting many weather and climate extremes such as heatwaves, heavy rains, droughts, and tropical cyclones in all parts of the world and the magnitude of recent changes in many aspects of the climate system is unprecedented in centuries. According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, it is clear that such climate change is a fact and is caused by human influence. It also states that, unless global CO_2 and other greenhouse gas emissions decline significantly over the next few decades, global average temperatures between 2021 and 2040 are likely to increase by 1.5 degrees Celsius compared to pre-industrial times (IPCC, 2021).

Korea is also not free from the effects of climate change. Recently, Korea has experienced extremely high temperatures, localized heavy rains, and mild winters due to climate change, which not only entails social and economic costs but also affects public health. In particular, 2020 recorded the longest rainy season (54 days in central standard) since 1973, and four typhoons landed in Korea one after another, causing property damage of KRW 1,259 billion and 46 casualties, which is about three times the average annual damage (property damage of KRW 388.3 billion, 14 people) in the last 10 years (Korea Meteorological Administration, 2021). In addition, Korea is experiencing serious air pollution. In Korea, air pollution had worsened due to rapid economic development and industrialization. Air pollutant emissions have increased due to the increase in registered vehicles and the expansion of electricity production, mainly coal-fired power plants. Recently in Korea, the problem of fine dust has become the most important issue. The worst concentration of fine dust ever recorded in March 2019 triggered it, which the daily average concentration of fine particulate matter ($PM_{2.5}$[1]) had risen to 135㎍/㎥, and the high concentration continued for 7 days with severe atmospheric stagnation.

Korea is currently in a situation where it is necessary to catch two birds with one stone. In the short term, Korea should improve air quality by reducing air pollutants, and in the long term, reducing greenhouse gases to prevent climate change. This can be seen through international comparison. Korea's greenhouse gas emission is the 11th largest in the world as of 2017 (GIR, 2020), and the annual average concentration of fine particulate matter is 27.45㎍/㎥ as of 2019, the worst level among OECD member countries (average 13.93㎍/㎥) (OECD, 2020).

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1) PM stands for particulate matter. $PM_{2.5}$ is fine inhalable particles, with diameters that are generally 2.5 micrometers and smaller. PM_{10} is inhalable particles, with diameters that are generally 10 micrometers and smaller.

To solve these problems, the cause of the problem must first be accurately defined. One of the main factors of climate change is greenhouse gases caused by increased fossil fuel use, and some air pollutants are known to not only deteriorate the quality of the atmosphere but also affect climate change. Climate change on a global scale and air pollution problems on a regional scale are being studied separately, but greenhouse gases and air pollutants emitted at the same time during fossil fuel combustion are closely related to each other. In particular, the 2006 IPCC Guidelines for National Greenhouse Gas Inventories stipulate air pollutants such as carbon monoxide (CO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) as indirect greenhouse gases is known to cause climate change and air pollution at the same time. Thus, among the various methods to solve these problems, if reducing the substances that affect them both is prioritized, the immediate effect will be visible.

1.2 Co-benefits of Greenhouse Gas Mitigation and Air Quality Management

1.2.1 What is "co-benefit"?

The issue of climate change is being dealt with as a common concern of all countries around the world, while the issue of air pollution is being dealt with as an individual national or regional concern. However, air pollution and climate change have many things in common. The sources of air pollutants and greenhouse gases are often the same. For example, the main sources of greenhouse gases such as CO_2, CH_4, and N_2O are mobile combustion, coal-electricity generation, agricultural soil management, natural gas systems, etc., which also emit air pollutants such as CO, NO_2, SO_2, and fine dust.

As such, air pollution and climate change have similar sources, so air pollution response policies contribute to mitigation of climate change, and climate change response policies also contribute to air pollution reduction. However, since the six greenhouse gases (GHGs; CO_2, CH_4, N_2O, HFCs, PFCs, SF_6) set by the Kyoto Protocol are not air pollutants, each policy to cope with the two problems has shown considerable gaps and has not been implemented efficiently and harmoniously.

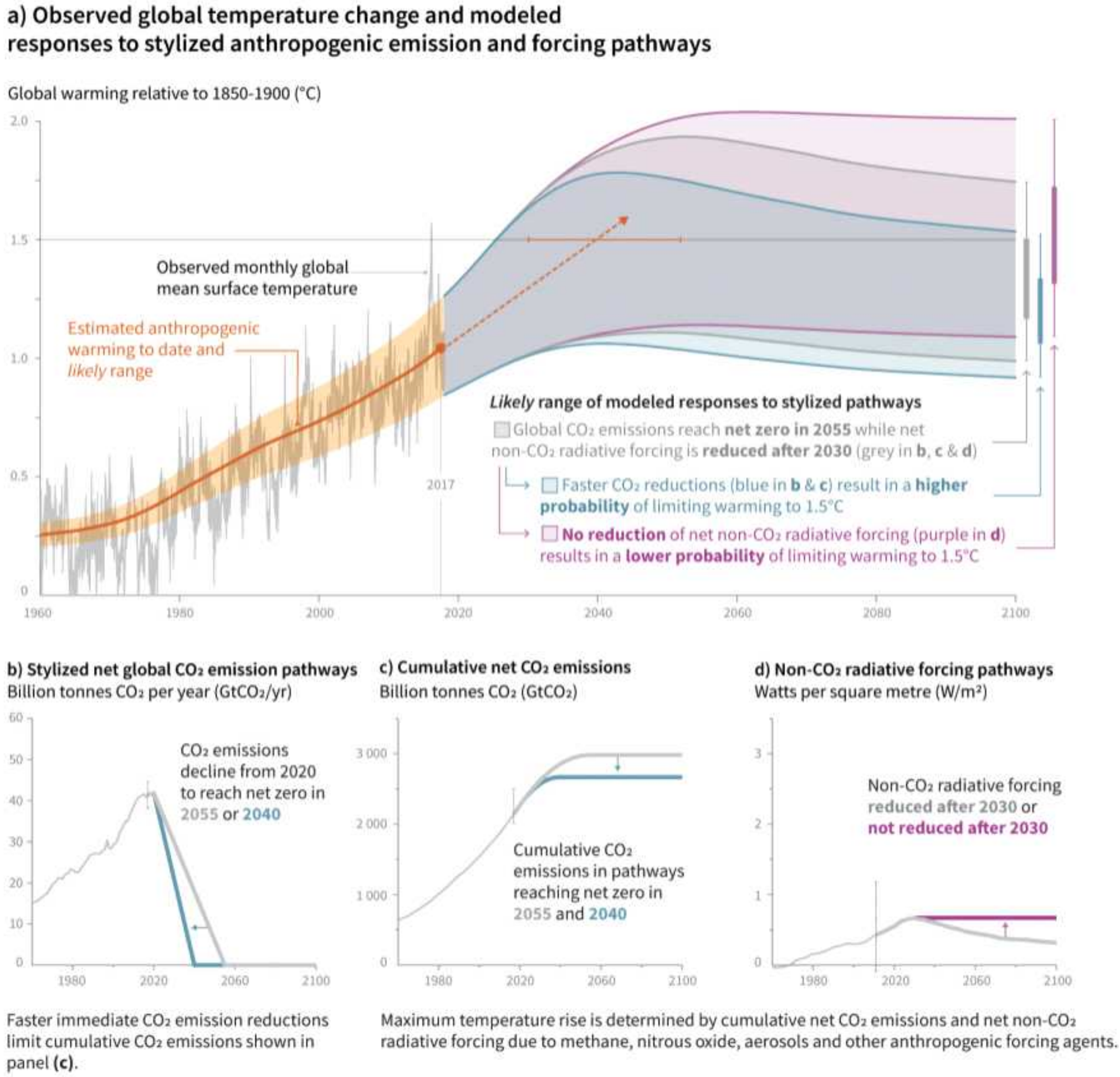
The Co-benefit approach refers to a strategy of acquiring both the benefits of responding to climate change and other benefits with one policy. The term "co-benefit" appeared in academic literature in the 1990s and attracted more attention by the time the Intergovernmental Panel on Climate Change's the Third Assessment Report (AR3) was published in 2001. The term "co-benefit" varies in scope and is generally used in the following three meanings. First, the "development co-benefits" includes the regional benefits that emerge through climate change policies. The benefits from this ranges from improving air quality, more advanced environmental technology, and creating better jobs. Second, "Climate co-benefits" means the benefits of responding to global climate change in development plans or sector-specific policies. This view emerged in response to the belief that developing countries would focus more on development than on responding to climate change. And the third, "Climate and air co-impacts" generally refer to multi-directional effects of air pollution interventions on local, regional and global climate systems. In other words, since the policy for climate change has a close impact on the improvement of air pollution, it is a view that emphasizes the benefits of pursuing improvement on both problems at the same time (ACP, 2010).

1.2.2 What is the merits of “co-benefit”?

Driven by rapid technological innovation and cost reduction, renewable energy has emerged as an important alternative to significantly reduce greenhouse gases in the energy sector. Although this utility of renewable energy is widely recognized worldwide and the technology development for it has been advanced, each country still forms a mainstream fossil fuel-based energy system. It also remains a serious threat to the Earth's climate system. Although the use of renewable energy has been increasing in recent years, the demand for energy is still rapidly increasing in many countries, and this is mainly supplied by the use of fossil fuels. In order to quickly respond to the proven global climate crisis, it is necessary to significantly weaken the path dependence of energy use and supply so far.

The IPCC estimates that human activity has caused about 1.0°C of global warming, and predicts that if global warming continues to increase at current rates, it is likely to reach 1.5°C between 2030 and 2052. In addition, many terrestrial and marine ecosystems and some of the services they provide have already been altered by global warming, and some impacts, such as the loss of ecosystems if global warming exceeds 1.5°C by 2100, will be long lasting or irreversible. (IPCC, 2018).

Figure 1. Cumulative emissions of CO_2 and future non-CO_2 radiative forcing determine the probability of limiting warming to 1.5°C (Special Report: Global Warming of 1.5°C)



In order to prevent a grim future caused by such climate change, various measures have been established and implemented around the world. In order to overcome the global climate crisis, almost all countries on the planet have come together to formulate joint measures, and have engaged in self-binding agreements and voluntary reduction efforts. These efforts so far do not seem to have effectively responded to climate change, which is rapidly progressing globally. Conventions based on spontaneity are not guaranteed to be binding, so they are ineffective, and unlike developed countries, developing countries that are pursuing development at the cost of environmental destruction do not actively participate in these efforts, citing equity in environmental pollution. It is difficult for countries around the world to effectively respond to climate change, but joint efforts for it are also very difficult.

However, the co-benefit approach to tackle climate change is that, unlike the existing climate policy method, which did not bring about realistic changes because it was norm-oriented, it can be expanded to benefit-oriented actions to ensure its effectiveness. When selecting priorities among various policy options to respond to climate change, a wiser choice can be made if the co-benefits linked to it are specified in order to calculate the benefits from them. For example, if a developing country replaces a small, inefficient coal power plant with a larger, more efficient power plant, the cost savings and air quality improvement effects will increase the effectiveness of the policy. In addition, if a country's energy mix is designed in the direction of increasing the proportion of renewable energy, it will be a measure to significantly reduce greenhouse gas, and at the same time, it will be possible to obtain the effect of creating new jobs and improving air quality. Therefore, the co-benefit approach is a method that can create multiple positive effects by maximizing the linkage effect between policies. Since this is also a method that can maximize the benefits of the policy, it induces voluntary choice of each country, so it is normatively and practically superior way.

1.2.3 Responding Climate Change and Air Quality Improvement from the “co-benefit” Perspective

Climate change mitigation policies can reduce emissions of air pollutants, for example by reducing fossil fuel combustion. In addition, gases such as black carbon and methane contribute to both climate change and air pollution, so reducing these substances has the advantage of curbing the rise in temperature and improving air quality on Earth. If coal-based energy can be replaced with renewable energy, it can effectively respond to climate change to mitigate global temperature increases in the long run, while significantly reducing social costs from air pollution. As such, climate change response policies are primarily based on ways to reduce substances that adversely affect the Earth's environment caused by human activities, which also reduce air pollution and have a positive effect on human health. Therefore, if costs are calculated around the benefits of climate change mitigation policies and policy priorities are set, the effectiveness of the policy can be maximized by maximizing the total benefits.

Greenhouse gases and air pollutants are produced as by-products related to human economic activities, such as fossil fuel use, and their negative effects, such as adverse effects on human health, ecosystem destruction and disturbance, can affect all areas of the environment. In addition, both greenhouse gas reduction measures and air pollution improvement measures have similar characteristics in many areas related to energy use and industrial activities. In addition, air pollutants such as ozone and aerosols change the process of generation and destruction due to climate change, and as a result, these substances affect climate change again, resulting in feedback action. Therefore, in addition to the policy of reducing greenhouse gas and air pollutants respectively, if substances that affect both at the same time can be reduced, it can be a way to maximize the interests in terms of co-benefits.

UNFCCC defines major air pollutants CO, NOx, NMVOCs, and SOx as indirect greenhouse gases, paying attention to the relationship between air pollutants and greenhouse gases, and stressing the need for integrated management of both substances. This can be said to be the structure of benefit maximization designed from the point of view of the co-benefit described above. Due to this importance, major countries such as the United States and Japan are already compiling indirect greenhouse gas inventories in their national inventory reports. However, in Korea, air pollutants and greenhouse gases are managed separately, so it is still inefficient from the point of view of co-benefits. Therefore, this report plans to study the relationship between CO, NOx, SOx, which are defined as indirect greenhouse gases and fine dust (PM_{10}, and $PM_{2.5}$), with which human activities are generated. In particular, if we analyze the characteristics of a city (a large city or a medium-sized city) in which various activities are continuing and the relationship between the substances and the characteristics of the city, it will be possible to propose an effective policy from the perspective of co-benefit.

1.3 Research Contents and Methods

This study was conducted to analyze substances generated in cities among various methods that can reduce climate change and air pollution at the same time. To efficiently reduce greenhouse gases and air pollutants such as fine dust, it is necessary to consider various factors and study many feasible solutions. However, in this study, considering the goal of drawing reasonable measures to simultaneously reduce climate change and air pollution, the characteristics of the urban sector were analyzed in depth with objective evidence. Although major sources of greenhouse gases and air pollutants exist across the region, this study focused on deriving policy implications by analyzing the characteristics of cities closely linked to modern human activities, such as population density, transportation, and industry. Urbanization is still going on nationwide, and if the trend of greenhouse gases and pollutants generated in cities is analyzed, it can be reflected in future urban planning to generate significant environmental benefits.

The research question for this study is as follows. What elements of the city are closely related to the number of substances such as NO_2, CO, SO_2, PM_{10}, and $PM_{2.5}$ in the air that cause climate change and air pollution? This is because, as mentioned earlier, NO_2, CO, SO_2 are substances that simultaneously accelerate climate change and air pollution, and PM_{10}, and $PM_{2.5}$ are currently the most important air pollutants in Korea. Therefore, if these substances and urban characteristics can be analyzed at a specific level to grasp their relevance and tendency, the occurrence of these substances can be suppressed and meaningful policy implications can be provided for future urban planning.

The target of this study is limited to big and middle cities with urban atmospheric measurement networks that can derive data on the current status of air pollution. Since this study needs to investigate accurate facts based on objectively measurable data, only data obtained in cities that have established a certified measurement network were used. In addition, human activities are more active in large and medium cities and various types of industries are maintained, so it is considered to be more representative as a source of greenhouse gases and pollutants. To answer the research question, first, this study examines the research methodology and research results on urban characteristics and air pollution through a literature review. In addition, this study classifies cities based on emissions and air pollution status by air pollutants, then analyzes the correlation using urban characteristics variables as independent variables and air pollutants as dependent variables.

Finally, after finding out the relationship between variables through regression analysis, this study will present policy implications for reducing substances that simultaneously cause climate change and air pollution.

Chapter 2. Air Pollution and Climate Change in Korea

2.1 The Current Status of Atmospheric Environment in Korea

2.1.1 Air Pollutants

2.1.1.1 Definition of Air Pollution

The World Health Organization (WHO, n.d.) defines air pollution as contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere. Household combustion devices, motor vehicles, industrial facilities and forest fires are common sources of air pollution.

Framework Act On Environmental Policy (Ministry of Government Legistration, n.d.) defines environmental pollution as follows: The term “environmental pollution” means air pollution, water pollution, soil pollution, sea pollution, radioactive contamination, noise, vibration, malodor, sunshine obstruction, light pollution from artificial lighting and other similar pollution caused by industrial activities and other human activities, such as inflicting damage on human health or the environment.

Clean Air Conservation Act (Ministry of Government Legistration, n.d.) defines air pollution as gas or particulate prescribed by Ordinance of the Ministry of Environment, which is acknowledged as a cause of air pollution as a result of the examination and assessment conducted under Article 7 among matters that exist in the air. This law sets 64 types of air pollutants, including gaseous substances (including odorous substances) such as sulfur dioxide (SO_2), carbon monoxide (CO), and nitrogen dioxide (NO_2) and particulate substances such as dust, of which 35 types such as cadmium are designated and managed as harmful substances to the specific atmosphere.

2.1.1.2 Sulfur Dioxcide

Sulfurous acid gas is a colorless, irritating, non-combustible gas that is easily soluble in water, and is generated from the combustion of coal and petroleum, which are fuels containing sulfur, metal smelting, and other industrial processes. When sulfur-containing fuel is burned, about 95% of the exhaust gas is in the form of SO_2 and the rest is in the form of SO_3 and sulfate. It takes about 4 hours for sulfur dioxide to halve in the atmosphere and about 25 days to completely disappear.

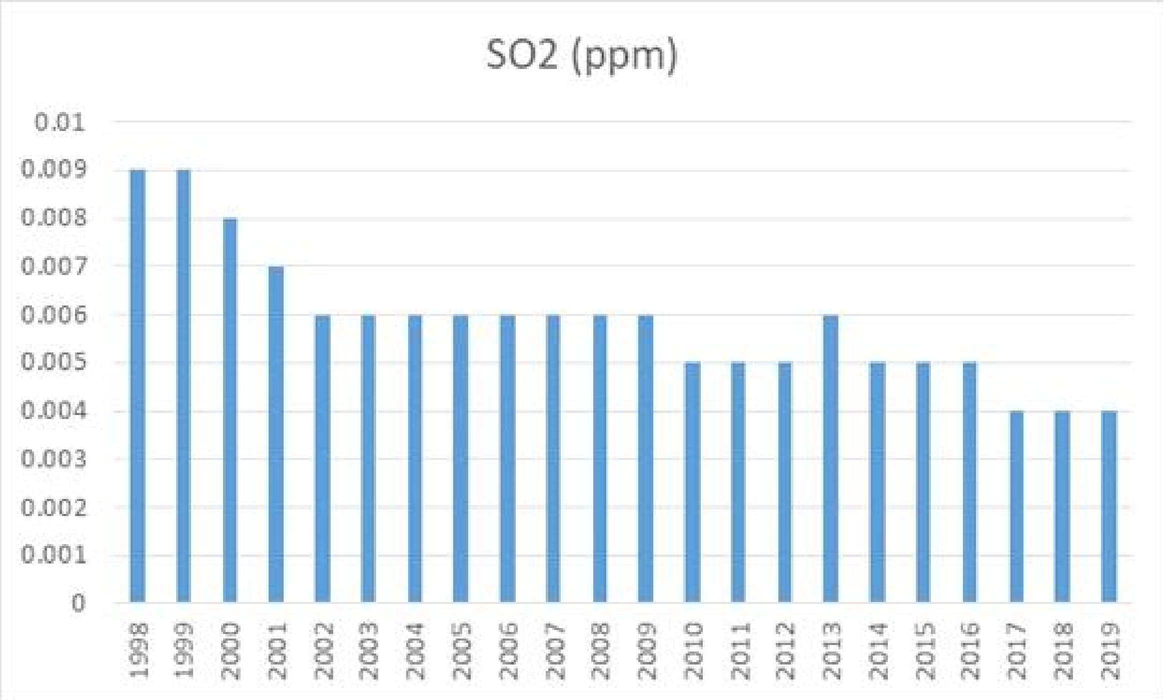
Sulfurous acid gas, along with nitrogen oxides, is a major cause of acid rain, affecting the acidification of soil, lakes, and rivers, and also promotes plant leaf vein damage, growth inhibition, and corrosion of various structures such as buildings and monuments.

Sulfurous acid gas irritates the mucous membranes of the human body, and when inhaled at high concentrations, runny nose, sweat, cough, etc. The higher the concentration of sulfurous acid gas, the faster you breathe, the more it is absorbed by the mucous membrane and the amount that reaches the bronchi increases, and the damage increases. Sulfur dioxide adsorbed on the mucous membrane reacts with mucus to form sulfuric acid, which eventually causes inflammation, which facilitates secondary infection by bacteria and viruses. There is also a study result that there is a possibility of contracting bronchitis, pulmonary edema, and pneumonia through inhalation of sulfur dioxide. Most of the air pollution damage cases are caused by sulfur dioxide. A typical example is the London Smog Incident, in 1952, smog occurred due to high humidity and stagnant air mass that lasted for seven days in London, England, resulting in more than 4,000 deaths from breathing disorders and suffocation.

Sulfurous acid gas is also a major cause of fine dust, which aggravates respiratory diseases such as asthma and deteriorates lung function (National Institute of Environmental Research, 2019).

In the case of Korea's SO_2 pollution level, the annual average pollution level is on the decline. There was no change from 2002 to 2009, and the annual average in 2010 was 0.005 ppm, a decrease of 0.001 ppm from the previous year. This is judged to be the result of government policies to reduce sulfur dioxide, such as the sulfur content standard system (1981), the solid fuel ban system (1985), and the mandatory use of clean fuels (1988). From 2019 to the present, the SO_2 concentration is maintained at 0.004 ppm, which is further decreased by 0.001 ppm (National Institute of Environmental Research, 2019).

Figure 2. Status of SO_2 Pollution Degree in Korea



2.1.1.3 Carbon Monoxide

Carbon monoxide is a colorless and odorless toxic gas that occurs when carbon components are incompletely burned. If oxygen is insufficient or the combustion temperature is low during combustion, complete combustion cannot occur, resulting in carbon monoxide, which is an incomplete combustion product. Therefore, carbon monoxide is contained a lot in the exhaust gas of automobiles, and when a large forest fire occurs, a large amount of carbon monoxide is generated due to insufficient oxygen, or when smoking, it is contained in cigarette smoke and discharged.

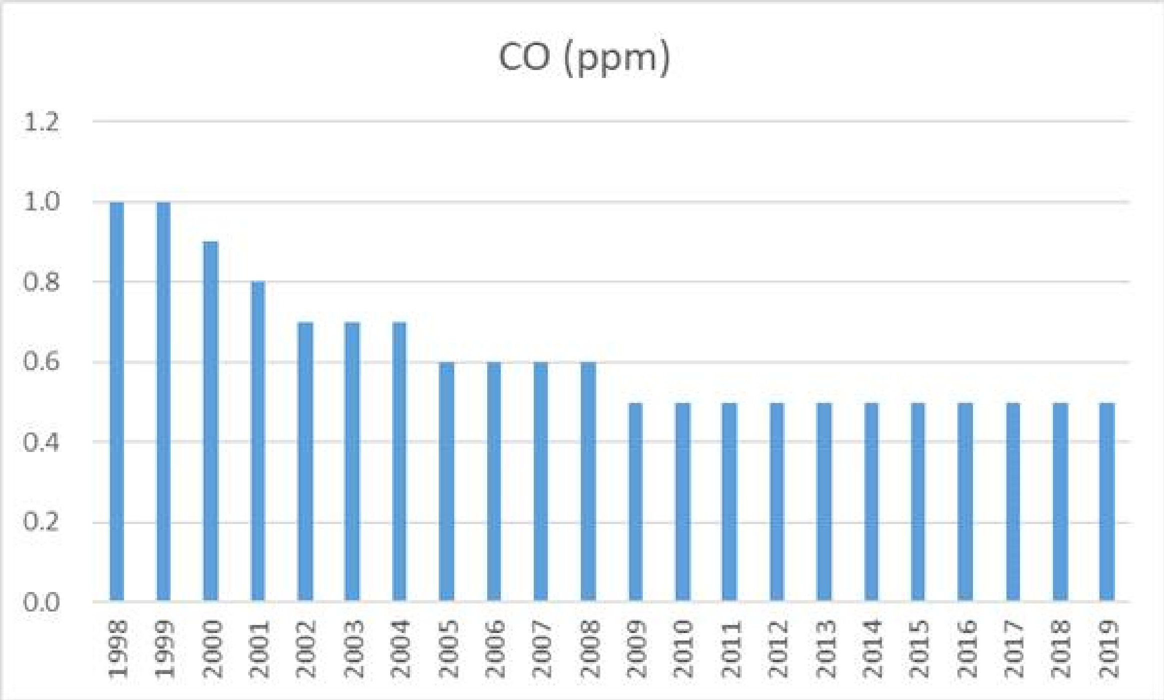
In Korea, heating fuel was the main source of carbon monoxide because of the high use of briquettes in the past, but now carbon monoxide emitted from automobiles is the main source of emissions as fuel conversion policies and the number of cars increased rapidly in the 1990s. In addition, there are natural sources such as fuel combustion in industrial processes and non-transmission sectors, forest fires, and indoor sources such as kitchen, tobacco smoke, and local heating.

Regarding the human effects of carbon monoxide, it combines with hemoglobin, which acts as an oxygen carrier in the body, reducing oxygen transport function, and in the case of high concentrations, it is toxic, causing fatal harm even to healthy people. Carbon monoxide sucked into the human body is emitted only through the respiratory tract, which is very slow (Ministry of Environment, n.d.).

In the case of indoor CO gas, it may negatively affect the human body, so thorough management is required. The concentration of CO discharged from a well-ventilated and well-adjusted gas range is about 5 to 15 ppm, and the concentration of CO near the poorly managed gas range may be higher than 30 ppm. Even in a house without a gas stove, the average emission concentration of CO gas is 0.5 to 5 ppm. Therefore, there is a need for a method for removing or keeping CO indoors low. In order to maintain good health by reducing exposure to carbon monoxide, it is most important to maintain proper combustion equipment at home. If high concentrations of CO are expected to occur in a short period of time, ventilation should be done more often, reducing the impact on the human body from this (Envitonmental Protection Agency, 2021).

In the case of CO pollution in Korea, the annual average pollution level is steadily decreasing. From 1999 to 2002, it decreased significantly from 1.0 ppm to 0.7 ppm. After that, the pollution level gradually decreased, and from 2009 to the present, it has been kept constant at 0.5 ppm (National Institute of Environmental Research, 2019).

Figure 3. Status of CO Pollution Degree in Korea



2.1.1.4 Nitrogen Dioxcide

Nitrogen dioxide is a reddish-brown, highly reactive gas, and is generated by oxidation of nitrogen monoxide in the atmosphere. Nitrous oxide is a colorless gas with a pungent odor that is slightly dissolved in water and sulfuric acid, and is brown when discharged at a high concentration in the atmosphere. And nitrogen dioxide is a red-brown gas with a pungent smell that dissolves in alkali and chloroform. Naturally, it is mainly produced by bacteria in the soil, and the concentration generated by natural causes in the atmosphere is very low, so it is not a problem. When reacting with volatile organic compounds in the atmosphere, it acts as a precursor to generate ozone.

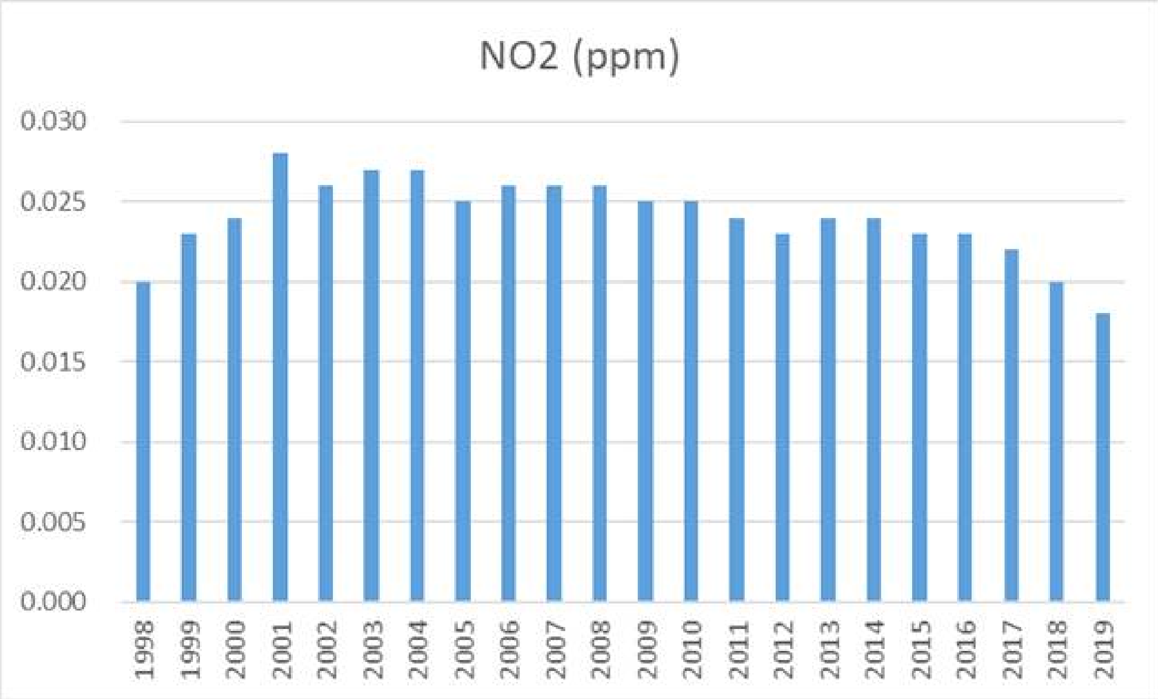
Nitrogen oxides are mainly generated during fuel combustion.

When fuel is burned at a high temperature, oxygen and nitrogen in the air react to produce it, and organic nitrogen in the fuel reacts with oxygen in the air to produce it. The main sources of emission are high-temperature combustion processes such as automobiles and power plants, and chemical substance manufacturing processes, and there is a natural generation by bacteria in the soil (National Institute of Environmental Research, 2019).

Various studies have shown that nitrogen dioxide has many adverse effects on the human body. In general, nitrogen monoxide and nitrogen dioxide do not exist alone, but exist together in many cases. Nitrogen oxide is known to cause more damage to the human body than nitrogen monoxide. In particular, there is a difference in damage in the exposure time according to the concentration. According to the results of epidemiological studies of diseases and the environment, long-term exposure to high concentrations of nitrogen dioxide causes problems in the heart circulation and blocks the flow of energy used throughout the body. In addition, it has been reported that, in severe cases, it may develop to the onset of chronic bronchitis, pneumonia, pulmonary hemorrhage, and pulmonary edema. Even when exposed to low concentrations for a long time, the phenomenon of diabetes, which slows the action of the vascular system, occurs in stages (Umweltbundesamt, n.d.).

In the case of NO_2 pollution in Korea, it deteriorated slightly every year from 1998 to 2001, but maintained a constant level without major change from 2002 to 2010. However, it slightly repeated increase and decrease from 2011 to 2014, and showed a decreasing trend from 2015, and the average pollution level in 2019 was 0.018 ppm (National Institute of Environmental Research, 2019).

Figure 4. Status of NO_2 Pollution Degree in Korea



2.1.1.5 Particulate Matter

Fine dust refers to a mixture of solid and spray particles in the air. These particles are emitted not only from natural sources but also from various types of fixed or mobile sources, and have various shapes and sizes. Fine dust is emitted directly from the emission source or is produced secondary by gaseous substances such as sulfur dioxide and nitrogen oxides (NOx). Fine dust is classified into PM_{10} and $PM_{2.5}$ according to its diameter. PM_{10} is dust smaller than 10/1000mm, and $PM_{2.5}$ is dust smaller than 2.5/1000mm, which is 1 of the diameter of a hair (about 60㎛). Particles smaller than 1/20 to 1/30 in size. Fine dust is generated from specific emission sources such as workplace combustion, automobile fuel combustion, and biological combustion processes.

A significant amount of $PM_{2.5}$ is produced secondary by reacting precursors such as sulfur oxides, nitrogen oxides, ammonia, and volatile organic compounds under certain conditions in the atmosphere. Naturally occurring particles include mineral particles such as yellow sand, salt particles, and biological particles such as pollen and microorganisms. The composition of fine dust is very diverse, and mainly consists of carbon components such as organic carbon and elemental carbon, ionic components such as sulfate, nitrate and ammonium, and mineral components.

The size and composition of fine dust are very complex and diverse, and it is known that the size, surface area, and chemical composition of the particles determine the health effects. Fine dust aggravates respiratory diseases such as asthma and causes deterioration of lung function. $PM_{2.5}$ particles are so fine that they are not filtered through the nasal mucosa and directly penetrate into the alveoli when inhaled, increasing the prevalence and premature death of asthma and lung diseases. In addition, fine dust deteriorates visibility, is deposited on the leaf surface of plants and interferes with metabolism, and is deposited on buildings, causing corrosion to sculpted relics and statues (National Institute of Environmental Research, 2019).

The current status of fine dust pollution in Korea is as follows. First, in the case of PM10, it has been gradually decreasing since the measurement in 1995. The concentration of PM_{10} in the atmosphere repeatedly increased and decreased from 55 ㎍/㎥ in 1998 to 58 ㎍/㎥ in 2007, but decreased significantly to 54 ㎍/㎥ in 2008. Since then, there has been a general downward trend until now. In 2012, it recorded 45㎍/㎥, which was a very low level. After that, it slightly increased, but as the pollution level decreased again, the pollution level recorded 41㎍/㎥ in 2019, maintaining a low level (National Institute of Environmental Research, 2019).

Figure 5. Status of PM_{10} Pollution Degree in Korea

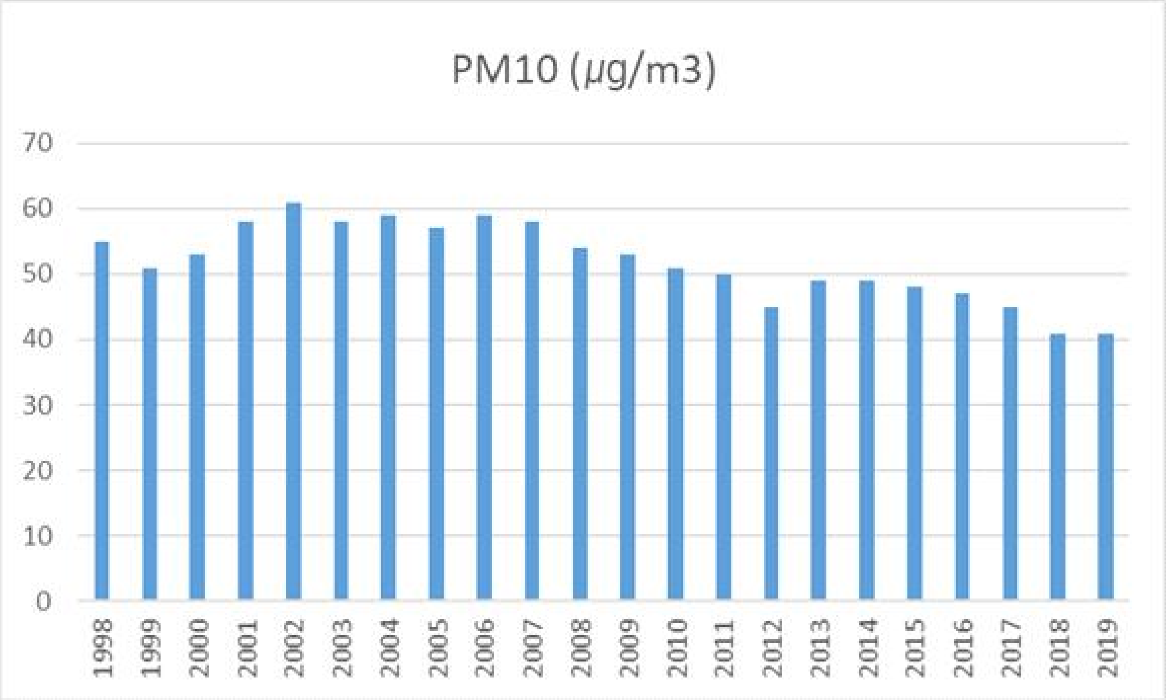
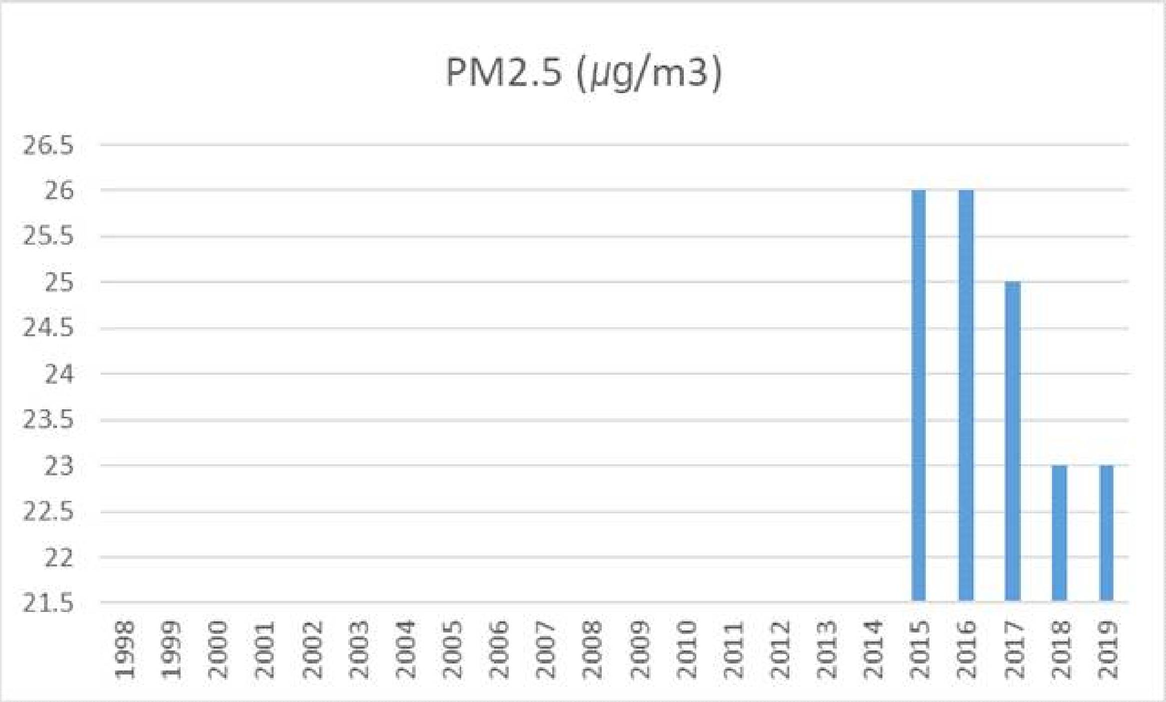


Figure 6. Status of $PM_{2.5}$ Pollution Degree in Korea



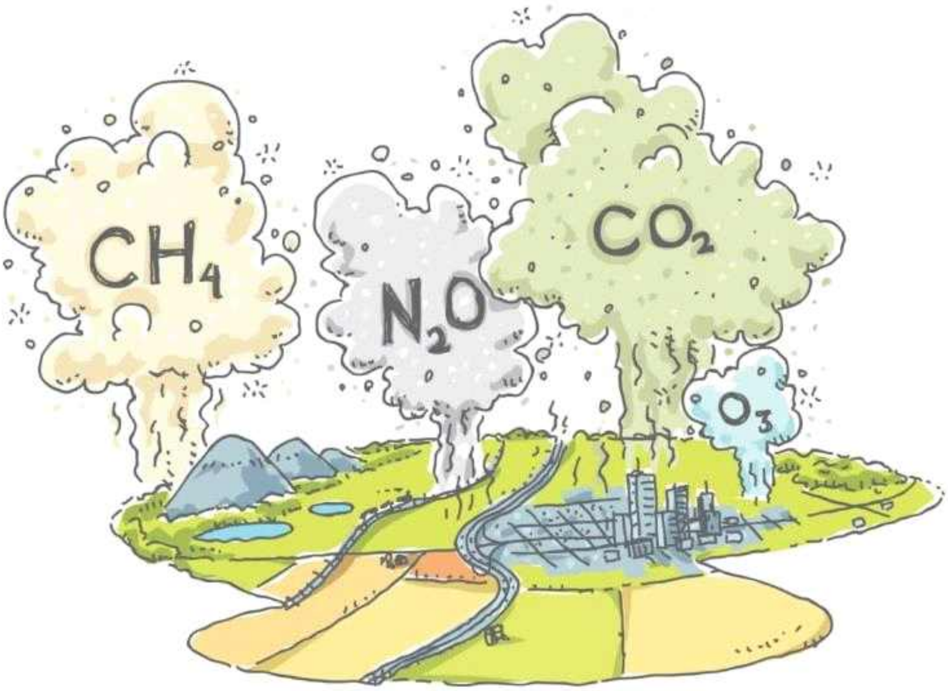
The official pollution level record of $PM_{2.5}$ started in 2015, because its air environment standard came into effect on January 1, 2015. In 2015, the atmospheric concentration of $PM_{2.5}$ was 26㎍/㎥, but it is gradually decreasing, recording 25㎍/㎥ in 2017 and 23㎍/㎥ in 2018 and 2019 (National Institute of Environmental Research, 2019).

2.1.2 Greenhouse Gases

2.1.2.1 The Status of Climate Change on the Earth

According to a report published by the World Meteorological Organization (WMO), ‘State of the Global Climate 2021: WMO Provisional Report‘, the average temperature of the Earth has risen by 1℃ for the first time over the past 20 years since 2002. In addition, global temperatures are expected to soar to an all-time high over the past seven years from 2015 to this year. This is due to the maximum greenhouse gas during this period. The report warned that such a rise in temperature has a global impact, driving the Earth we live in into an "uncharted territory." The WMO also predicted that 2021 will be the fifth to seventh hottest year ever based on data over the past nine months. The average temperature of the Earth in 2021 is expected to be about 1.09℃ higher than before industrialization.

In addition, the report cited rising global temperatures as a serious concern as well as rising global sea levels. Since the sea level began to be measured with a precise satellite-based system in the early 1990s, it has risen 2.1mm every year from 1993 to 2002. However, from 2013 to 2021, the increase jumped to 4.4mm, twice the figure over the past decade, and the biggest reason is that glaciers and ice sheets melted faster (World Meteorological Organization, 2021).



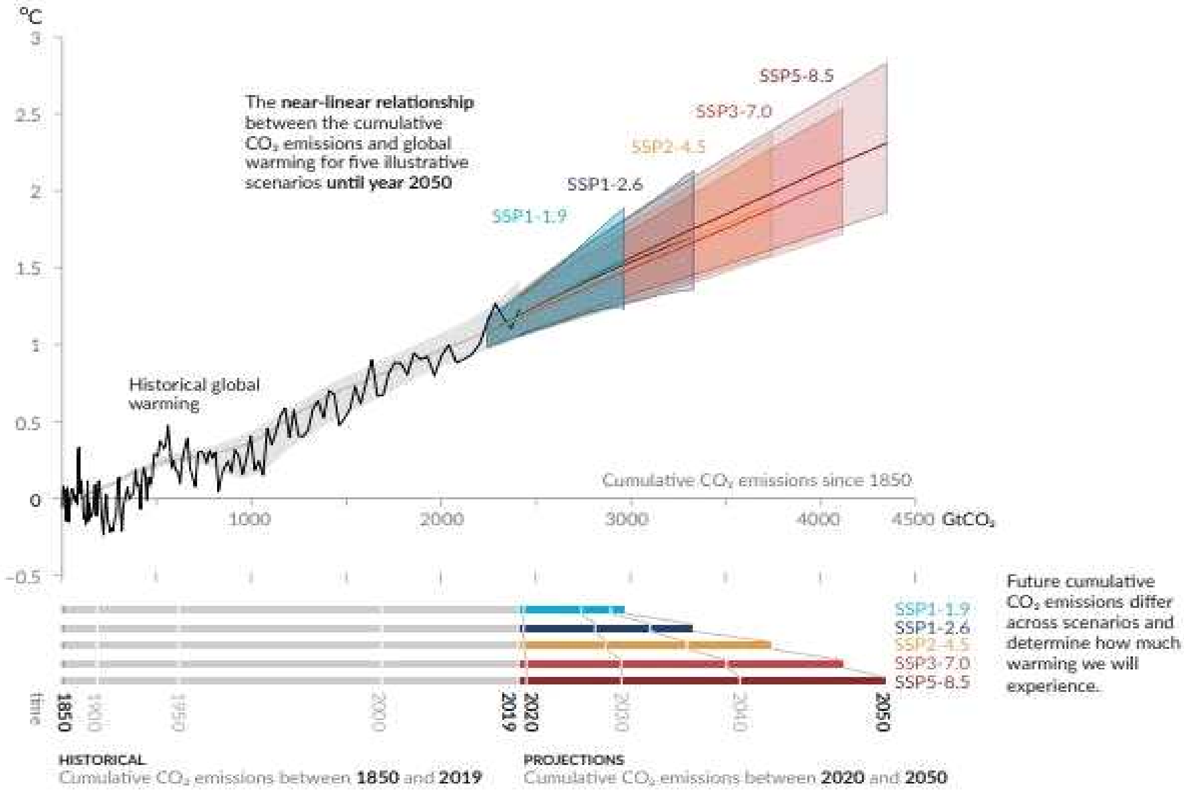
Retrieved March 5, 2022, from https://www.science-sparks.com/know-your-greenhouse-gases/

In 2015, the international community set a goal of keeping global temperature rise within 2℃ and below 1.5℃ if possible, compared to before industrialization to prevent global warming disasters in the Paris Climate Agreement. However, instead of approaching the achievement of these goals, the Earth seems to be getting farther and farther away from it now. Record-breaking heatwaves that hit North America in the summer of 2021, large-scale floods in Europe such as Germany, and Death Valley in California, USA, soaring to 54.4℃, suggesting a recent abnormal climate, and are often diagnosed as "New Normal."

According to the Fift Assession Report (AR5) released in 2014 by the Intergovernmental Panel on Climate Change (IPCC), jointly established by the World Meteorological Organization (WMO) and the United Nations Environmental Program (UNEP), global average temperature has risen by 0.85°C over the past 133 years (1880-2012) and the global sea level has risen by 19 ㎝ from 1101 to 1901. It also revealed that the average annual area of Arctic sea ice over the past 34 years (1979-2012) is likely to have decreased by 3.5 to 4.1% in 10 years. If greenhouse gases are emitted at the current trend, the global average temperature at the end of the 21st century (2081-2100) is expected to rise 3.7°C and 63m compared to 1986-2005) (Intergovernmental Panel on Climate Change, 2014).

On August 9, 2021, the IPCC approved "the first Working Group Report of the Sixth Assessment Report (AR6)" which said, "If greenhouse gas emissions are maintained at the current level until the middle of this century, it is likely to exceed 1.5℃ global warming between 2021 and 2040. In other words, the time of arrival of global warming at 1.5°C has been advanced from 2030-2052 presented in the Special Report on Global Warming of 1.5°C (2018). This report presented the results of climate change analysis using newly observed facts and advanced technologies since the publication of the 5th Assessment Report (AR5, 2013), and it is said that the global surface temperature rose 1.09℃ between 2011 and 2020 compared to before industrialization (1850-1900). In addition, the global surface temperature between 2081 and 2100 compared to before industrialization is expected to rise by 1.0 to 1.8℃ in scenario (SSP1-1.9) that emits the least greenhouse gases and 3.3 to 5.7℃ in scenario (SSP5-8.5) that emits the most greenhouse gases. The report reaffirmed the AR5 results that there is almost a linear relationship between CO_2 emissions accumulated by human activity and global warming, and stressed that only limiting CO_2 emissions through carbon neutrality and strong reductions in emissions of other greenhouse gases such as methane can curb global warming (Intergovernmental Panel on Climate Change, 2021).

Figure 7. The relationship between accumulative CO_2 emissions and global surface temperature (AR6)



2.1.2.2 Current Situation of Climate Change in Korea

Recently, meteorological disasters caused by climate change have frequently occurred in Korea, affecting various fields such as economy, society, and the environment. In 2018, Korea recorded the lowest temperature since 1973, while the daily maximum temperature was measured at 41°C in Hongcheon due to a long-term heatwave, the highest in history, and Seoul also recorded an extreme value in 111 years (from 1907). In addition, it ranked first in observation history with 31.4 days of heat wave (9.8 days per year) and 17.7 days of tropical night (5.1 days per year).

As such, the future outlook for Korea, where the impact of climate change is becoming a reality, is as follows. In Korea, annual average temperature, precipitation, and sea level rise are observed, and warming continues, with the average temperature of six cities (Seoul, Incheon, Gangneung, Daegu, Busan, and Mokpo) rising by 0.18˚C every 10 years over the past 106 years (1912-2017). In addition, the annual precipitation has increased by a width of about 16.3 mm over the past decade, and the water temperature and sea level growth rate in the surrounding seas of Korea are observed to be about two to three times higher than the global average of 0.85˚C and 1.4 ㎜/year. If Korea emits greenhouse gases according to the current trend, the average temperature in the second half of the 21st century (2071-2100) is expected to rise 4.4˚C compared to the current (1981-2010), precipitation increases 13% compared to the present, and heat waves and tropical nights increase 3.5 times and 11.9 times, respectively (Ministry of Environment, 2020).

2.1.2.3 Climate Change Prospects by Sector in Korea

Korea cannot be free from global climate change either. The four distinct seasons are already disappearing, the ecosystem is finding a new balance, and the damage caused by heatwaves and heavy rains is increasing year by year. Although it is not possible to know exactly how Korea's climate change will go, the future climate change patterns of Korea predicted by experts and research are explained by field as follows (Ministry of Environment, 2021).

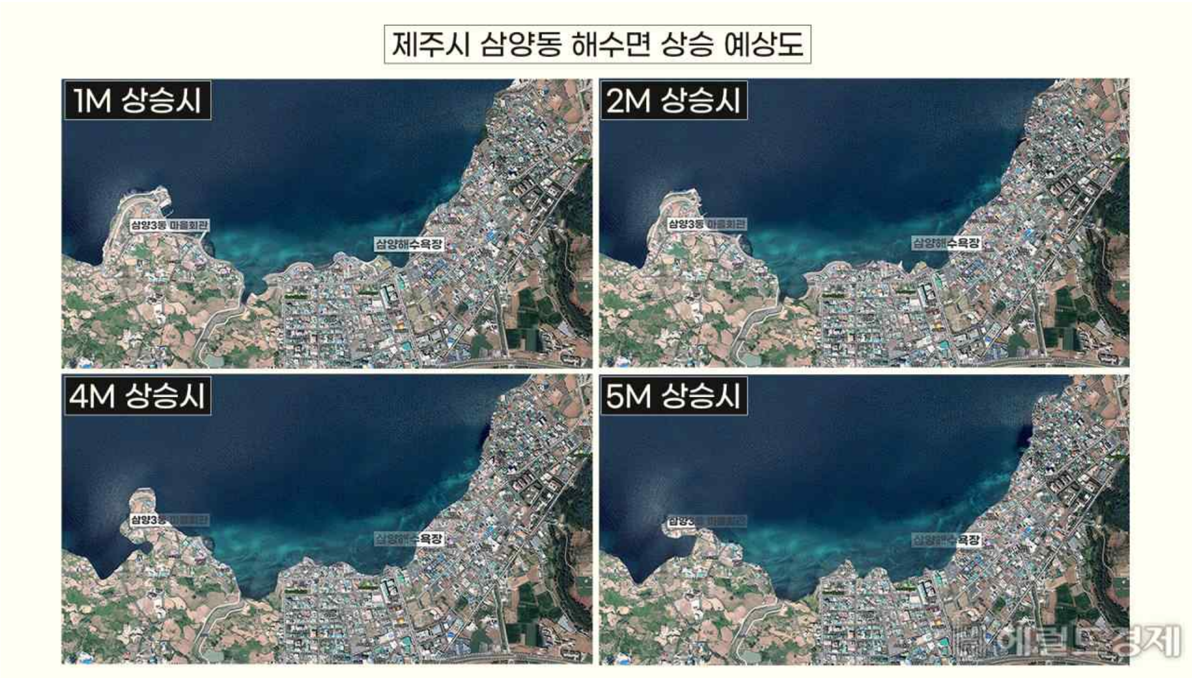
① Water

The amount of groundwater in Korea is expected to decrease. The amount of rainwater that does not permeate into the soil and directly drains from the surface will increase in the future, and the rate of change is also expected to increase. It is expected that the frequency of concentrated rainfall will increase the outflow of water from the surface, and the amount of groundwater will decrease as snowfall is also reduced, which will intensify the shortage of water resources. Climate change will increase the amount of flooding, which will further increase the risk and vulnerability of floods compared to the present. Although the frequency and severity of droughts may vary regionally, they are expected to increase overall. Therefore, it is expected that the water shortage will be more serious in areas with frequent droughts. The seasonal effects of drought will intensify the drought in spring and winter.

② Ecosystems

In accordance with climate change in Korea, the average annual temperature increased and precipitation increased, changing the seasons of plants and the distribution of plants and animals. In the future, it is expected that the flowering period of plants will be accelerated due to the increase in temperature due to the increase in CO_2 concentration, the distribution area of cold-tropical plants will be reduced, and the distribution area of warm-tropical plants will be expanded.

The distribution of temperate evergreen broadleaf forests is expected to move northward by about 80 km from the west and east coasts when the average temperature of Korea rises by 0.5°C. It is expected that the distance to the north of the east and west coasts is similar, but the area of the west coast is wider. Compared to the past, it is expected that temperate evergreen broadleaf forests of Jeju Island will expand by about 2 km in the mountainous area in recent years, and will expand by 1-2 km in the future. In terms of elevation, it is predicted to be distributed up to an altitude of about 360 m above sea level.



③ Forest

As the average annual temperature in Korea rises, the forest composition of each region is changing, and the inflow and spread of pests has been confirmed. The forest distribution is predicted to decrease coniferous forest and increase in broadleaf forest. As a result of monitoring and forecasting the forest distribution according to climate change, it was found that forests and broadleaf trees in alpine areas were declining, and vegetation changes throughout Korea were predicted. Therefore, from the viewpoint of coping with climate change, management and adaptation strategies are needed to increase the role of forests as a carbon sink. As for pests, it is expected that subtropical pests will continue to flow in and settle in the future.

④ Agriculture

As the climate warms, the viability period of field crops is lengthening. The first frost is delayed and the late frost is early, so the frost-free period is noticeably longer. The variability of the climate has also increased, and the occurrence of extreme weather such as heat waves, heavy snow, cold waves, and heavy rains and the resulting damage to crops are rapidly increasing, while the annual frequency of occurrence of extreme low temperatures has greatly decreased. However, as the germination and flowering period of plants accelerated due to warming, damage from low temperatures is expected to exist.

The occurrence of pests and diseases is increasing with global warming. Korea, belonging to a temperate climate zone, will gradually change to a subtropical zone, and the types and methods of crops that can be cultivated in Korea will change, and accordingly, the occurrence pattern of pests and weeds is expected to change. The vulnerability of rice production by pests will be higher in the future than in the present, and the area of vulnerable areas is expected to increase.

⑤ Ocean and Fisheris

Sea level rise due to global warming, changes in ocean currents, and ocean acidification are observed, and the progress is faster than changes in the global ocean. The warming of water temperature in Korea is expected to continue, and changes in the structure of the food web and major fish species are predicted. In the past 40 years, the surface water temperature of the Korean ocean has risen by 1.0˚C, and Korea is one of the regions where the water temperature is increasing the fastest in the world.

The increase in surface water temperature in the coastal waters of Korea has various effects on the fishery industry in the coastal waters. There is no significant change in the overall catch, but relative catches in coastal fisheries are decreasing and catches in offshore fisheries are increasing. Currently, the main fish to be caught are moving northward, and new subtropical fish are increasing, so it is expected that the fishing method and species will change in the future.

⑥ Industry and Energy

Changes in the summer temperature pattern and winter climate due to climate change, along with an increase in electricity consumption and changes in usage methods, are expected to lead to huge changes across industries and energy sectors. The adverse effects of climate change are expected to vary according to the size and type of domestic industrial complexes.

From an industrial perspective, climate change itself can be a cause of vulnerability. An increase in the overall temperature and a decrease in the number of days of precipitation increase the number of days available for outdoor work such as construction, but an increase in the frequency of heavy rain can lead to damage such as site flooding, loss of construction materials, and safety accidents. As a result of the perception survey of the domestic industry, the power generation and chemical industries are expected to have a negative impact from climate change, while the metal industry is expected to have a relatively low impact. In particular, in the case of companies that are expected to have a negative impact from climate change, it was found that the performance of forming a climate management system or a climate-related organization was high.

In terms of power transmission and distribution in the energy sector, a plan for safe housing in preparation for disasters should be established with buildings including the concept of temporary housing for recovery in case of natural disasters in urban areas due to climate change. Although climate change has a significant impact on industry and energy, sufficient research is needed on the overall impact and specific shape, and a specific strategy for climate change adaptation through impact analysis and evaluation is needed.

⑦ Health

Correlations with climate change such as the incidence of patients and deaths due to heat waves, allergy sufferers, and malaria have already been confirmed. In the case of Korea, as the duration of the heat wave becomes longer, it is expected that the number of deaths, allergic diseases, and water-related ailments will increase. The number of deaths in the future (2036-2040) in the Seoul area due to heat waves is expected to more than double from 0.7 to 1.5 per 100,000 population compared to the present.

By the end of the 21st century, it is predicted that the CO_2 concentration will be about double the current level, and the pollen season of birch trees will be about one month earlier and the concentration will increase by about 50%. Therefore, it is expected that the pollen season of trees and herbs due to climate change will increase and exposure will also increase.

2.1.2.4 Inventory of Korea's Greenhouse Gas Emissions

Korea's total greenhouse gas emissions (excluding LULUCF; Land-Use, Land-Use Change and Forestry) in 2018 were 727.6 million tons CO_2eq., an increase of 149.0% compared to the total emissions of 292.2 million tons CO_2eq. in 1990, and 2.5% from the total emissions of 709.7 million tons CO_2eq. in 2017. Net greenhouse gas emissions (including LULUCF) in 2018 were 686.3 million tons of CO_2eq., an increase of 169.8% from 254.4 million tons of CO_2eq. in 1990, and an increase of 2.7% from 668.3 million tons of CO_2eq. in 2017.

The energy sector with the highest emissions emitted 632.4 million tons of CO_2eq (86.9% of the proportion) in 2018. The industrial processes and product use sector emitted 57.0 million tons of CO_2eq. (7.8% of the proportion), the agriculture sector 21.2 million tons of CO_2eq. (2.9% of the proportion), and the waste sector 17.1 million tons of CO_2eq. (2.3% of the proportion).

The areas that contributed the most to the increase in emissions in 2018 were energy sector, up 16.7 million tons of CO_2eq. and 2.7 percent year-on-year, and mainly in the public electricity and heat production and chemicals industries. Emissions in the public electricity and heat production increased by 17.0 million tons of CO_2eq. and 6.7% year-on-year due to the increase in natural gas generation due to the increase in electricity demand. It is analyzed that the increase in emissions (5.3 million tons CO_2eq., 3.1%) in the chemicals industry is due to the increase in the production of basic oils (ethylene, propylene, butadiene, benzene, toluene, and xylene).

Table 1. Greenhouse Gas Emissions and Sinks by IPCC Sector in Korea

(MMT CO_2eq.)

Category	Greenhouse Gas Emissions							The Rate of Increase (1990)	The Rate of Increase (2017)
	1990	2000	2010	2015	2016	2017	2018		
Energy	240.4	411.8	566.1	600.7	602.7	615.7	632.4	163.1	2.7
Industrial Processes and Product Use	20.4	50.9	53.0	54.3	53.2	55.9	57.0	178.7	1.9
Agriculture	21.0	21.4	22.1	21.0	20.8	21.0	21.2	1.0	1.1
LULUCF	-37.8	-58.4	-53.8	-44.4	-45.6	-41.5	-41.3	9.3	-0.5

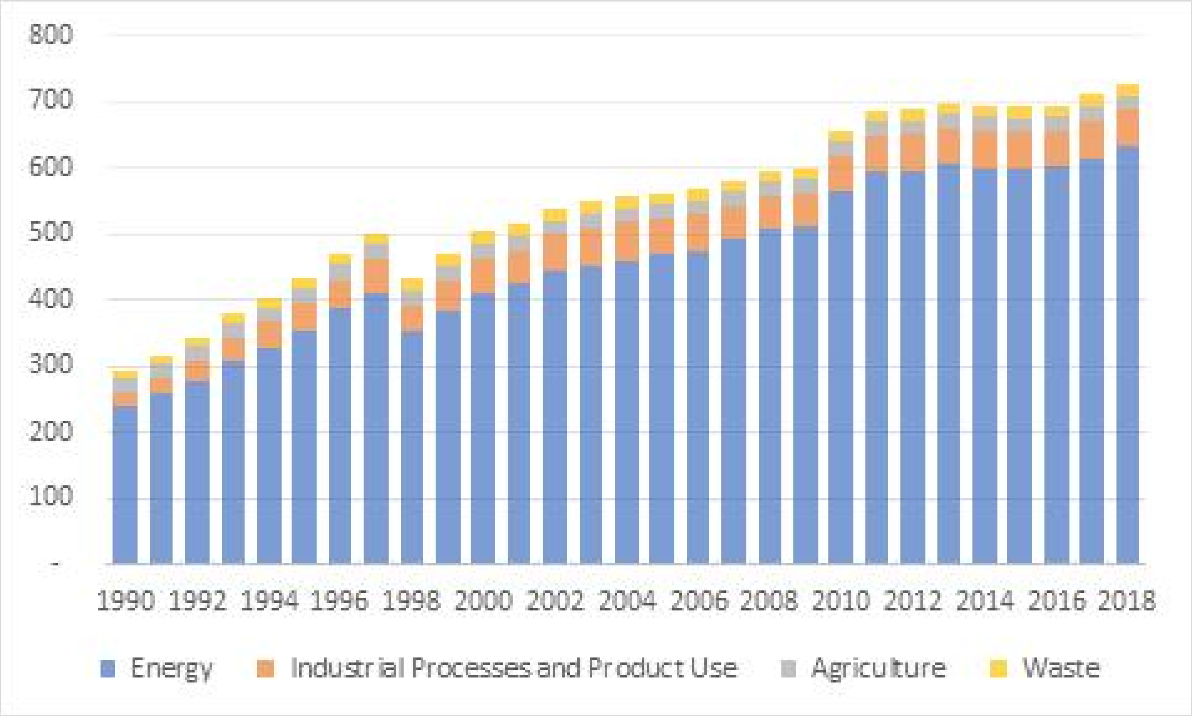
Waste	10.4	18.8	15.2	16.6	16.8	17.2	17.1	64.7	-0.7
Toral Gross Emissions*	292.2	502.9	656.3	692.5	693.5	709.7	727.6	149.0	2.5
Net Emission**	254.4	444.5	602.5	648.2	648.0	668.3	686.3	169.8	2.7

* Total emissions without LULUCF
** Net emissions with LULUCF.

The trend of total greenhouse gas emissions in Korea by year is as follows. In the 1990s, Korea was in a period of economic growth, so greenhouse gas emissions increased significantly. During the 1990-1999 period, Korea's total greenhouse gas emissions increased by an annual average of 5.4%, and during the same period, Real Gross Domestic Product (GDP) increased by an annual average of 6.9%. Since GDP decreased by 5.1% year-on-year due to the financial crisis of foreign exchange shortage in 1998, and greenhouse gas emissions in Korea decreased by 14.1%.

On the other hand, in the 2000s, greenhouse gas emissions steadily increased as Korea's economy recovered, but the growth rate tended to gradually slow down. The average annual growth rate of total emissions from 2000 to 2009 was 1.9%, especially in 2009, greenhouse gas emissions increased by only 0.7%, due to the economic downturn. From 2010 to 2018, greenhouse gas emissions increased by 1.3% annually, showing a lower rate of increase than in the 1990s and 2000s. In 2014, Korea's total greenhouse gas emissions decreased by 0.8% year-on-year, the first case of decline except for those in 1998. In 2018, the latest, total emissions increased by 2.5% year-on-year due to the increase in emissions in the energy sector (Greenhouse Gas Inventory and Research Center, 2021).

Figure 8. Korea’s. Greenhouse Gas Emissions by IPCC Sector/Category (1990-2018)



2.2 United States Climate Change Policy

Joseph R. Biden, the 46th President of the United States, is pursuing active and strong policies to cope with climate change. On the first day of his presidency ('21.1.20), he formalized the re-entry of the Paris Agreement and confirmed that a significant portion of the $2.25 trillion infrastructure investment plan would be invested in green infrastructure-related projects ('21.3.31). It also reaffirmed its goal of reducing greenhouse gas emissions by half in 2030 compared to 2005 levels, achieving carbon neutrality in the power generation sector by 2035, and achieving national carbon neutrality by 2050 ('21.4.21).

The United States promotes policies in the way of an Executive Order while solidifying clear goals and directions for responding to climate change. This method has the advantage of being able to implement measures quickly and timely because it does not go through parliamentary legislation, but has the disadvantage of not being able to implement strong policies beyond the law, difficulty in using the budget without parliamentary approval, and difficulty in continuing the policy stance to the next administration. In addition, since clear boundaries are not clear about the limitations of executive orders, frequent legal lawsuits are likely to continue.

The main executive orders related to the Biden administration's response to climate change are as follows (Executive Office of the President, n.d.).

Table 2. Executive Orders on Tackling the Clmate Change in U.S.

	Date Signed	Publication Date	Order Number	Order Title
① EO 13990	'21.1.20	'21.1.25	2021-01765	Protecting Public Health and the Environment and Restoring Science To Tackle the Climate Crisis
② EO 14008	'21.1.27	'21.2.1	2021-02177	Tackling the Climate Crisis at Home and Abroad
③ EO 14030	'21.5.20	'21.5.25	2021-11168	Climate-Related Financial Risk
④ EO 14037	'21.8.5	'21.8.10	2021-17121	Strengthening American Leadership in Clean Cars and Trucks
⑤ EO 14057	'21.12.8	'21.12.13	2021-27114	Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability

① Protecting Public Health and the Environment and Restoring Science To Tackle the Climate Crisis (EO 13990, ’21.1.25): This executive order aims to strengthen resilience to climate change impacts to reduce greenhouse gas emissions. To this end, in order to reduce methane emissions in the oil and gas sectors, emission standards for new, reconstructed, and modified emission source inventories will be prepared by September 21. It also accurately identifies the overall cost of greenhouse gas emissions, facilitates sound decision-making to cope with climate change, and supports international leadership in the United States.

② Tackling the Climate Crisis at Home and Abroad (EO 14008, ’21.2.1)

- (Diplomacy) Since climate is an essential element of diplomacy and national security, the United States promotes bilateral and multilateral international cooperation around the world to secure a sustainable climate path. This includes hosting the climate summit, reconvening major economic forums on energy and climate, creating the Special Presidential Envoy for Climate, and immediately starting the process of developing nationally determined contribution (NDC).

- (Organization) The White House Office of Domestic Climate Policy (Climate Policy Office) will be established within the Executive Office of the President to coordinate the policy-making process on climate issues and provide advice on domestic climate policy. In addition, a government-wide plan will be established to cope with the climate crisis and the ‘National Climate Task Force’ will be established to increase resilience to climate change.

- (Renewable Energy) Double offshore wind power by 2030, protect land, sea and biodiversity and create decent jobs.

- (Subsidy) Do not subsidize fossil fuels directly, and seek to remove them from budgets for fiscal year 2022 and beyond.

- (Adaptation) Each agency develops an agency's adaptation plan to improve the energy and water efficiency of facilities and buildings, and to prepare for climate.

- (Agriculture/Forest) Conserve and restore public land and water, strengthen community resilience and expand reforestation.

- (Environmental Justice) Develop programs, policies and activities to address disproportionate health, environmental, climate and other impacts on disadvantaged communities and the accompanying economic challenges.

③ Climate-Related Financial Risk (EO 14030, ’21.5.25) : Climate change presents opportunities to strengthen United States' competitiveness and economic growth and create high-paying jobs, while increasing physical risks to assets, securities, private investment and businesses. Therefore, the federal government measures and evaluates climate-related financial risks to programs, assets and liabilities to increase the long-term stability of operations. In addition, the United States will achieve net-zero emissions by 2050 and finance adaptation to the acute and chronic impacts of climate change. Expand economic opportunities, empower workers and mitigate environmental impacts in disadvantaged and communities of color.

④ Strengthening American Leadership in Clean Cars and Trucks (EO 14037, ’21.8.10) : Strengthen the domestic market by setting a target to make 50% of all new passenger cars and light trucks sold by 2030 eco-friendly, including electric and fuel cell vehicles. In addition, the pollutant emission standards and fuel efficiency standards for passenger cars and light-duty trucks beginning with the model year 2027 and heavy-duty pickup trucks and vans beginning with the model year 2028 will be strengthened.

⑤ Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability (EO 14057, ’21.12.13) : Achieving carbon pollution-free electricity by 2035 and achieving net-zero overall economy by 2050. The federal government will acquire 100% of zero-emission light vehicles by 2027 and 100% of net zero-emissions vehicles by 2035. In addition, each agency will achieve zero greenhouse gas emissions for all buildings by 2045, including a 50% reduction in greenhouse gas emissions from buildings by 2032. (Reduce greenhouse gas emissions from buildings, campuses and facilities by 50% of 2008 levels by 2032, ban fossil fuels, and net zero new construction and modernization projects totaling more than 25,000 square feet by 2030 designed as). By 2030, reduce greenhouse gas emissions from federal operations by 65% of 2008 levels and achieve net zero emissions from federal procurement to promote the use of low-emission building materials. By 2025, divert at least 50% of non-hazardous solid waste from landfills each year, including food waste, compostable waste and construction waste. (75% by 2030).

Chapter 3. Literature Review

3.1 Urban Characteristics

This study started from the assumption that factors according to urban characteristics would have a direct or indirect relationship with the emission of air pollutants. Therefore, through the literature review, which characteristics of a city affect air pollution, and how each characteristic increases/decreases air pollution is identified, and then the most important implications of this study will be suggested.

In general, air pollutants such as CO and NOx[2] are generated from activities such as fuel combustion and transportation. Looking at

2) The term NOx is chemistry shorthand for molecules containing one nitrogen and one or more oxygen atom.

the papers comparing air pollution and urban characteristics, many studies are analyzing these activities. Many empirical studies have shown that urban morphology, such as city size, shape, fragmentation, and population density, has a significant impact on air pollution. For example, Clark et al. (2011) in a study of 111 urban areas in the United States found that population density was associated with higher population-weighted $PM_{2.5}$ concentrations, and population centrality was associated with lower population-weighted ozone and $PM_{2.5}$ concentrations, and that transportation supply was associated with lower population-weighted $PM_{2.5}$ concentrations. Also, according to Cho and Choi's research (2014), compact cities increase population density, which may increase local NO_2 concentrations in Korea.

3.2 Factors Influencing Air Quality

3.2.1 Transportation

The primary relevant literature on the relationship between air pollution and transportation is Air pollution and Urban Structure Linkages: Evidence from European cities (Cárdenas Rodríguez et al., 2016). This paper explores the relationship between urban characteristics and concentrations of air pollutants (NO_2, SO_2, PM_{10}) using samples from 249 European metropolitan areas. The results of the study suggest that overall, the effects of economic, social demographic, and land cover variables have different effects depending on pollutants. In particular, it was concluded that traffic activity had a positive correlation with PM_{10} and NO_2 concentrations and that higher population density was associated with higher SO_2

concentrations. These findings show that the problem of increasing NO_2 and PM_{10} concentrations due to the further expansion of European urban areas can be partially addressed by urban spatial policies. Because continuous urban areas improve connectivity, reduce reliance on vehicles, and facilitate the use of non-motorized modes of transport such as bicycles and walking. Also, spatial policies leading to reduced population density may partially alleviate concerns about SO_2 emissions. In conclusion, this paper suggests that sparsely populated and continuous cities in Europe can improve air quality.

Some studies show that structural changes in cities lead to changes in transportation, resulting in more greenhouse gas emissions. Bart (2010) uses a simple linear multiple regression analysis for the EU Member States for which data is available to determine the relationship between population changes, gross domestic product, and artificial land area and changes in road transport emissions between 1990 and 2000. The results of the analysis showed that sprawl explains more fluctuations in road transport emissions growth than population growth and GDP per capita. In the EU, unlike other sources, greenhouse gases generated from transportation are continuously increasing. If it is necessary to reduce greenhouse gas emissions from the transportation sector to improve air quality, policies such as the distribution of eco-friendly vehicles are not sufficient, and the introduction of a sprawl restriction policy should be considered.

In addition, there is an empirical analysis of how these transportation changes affected air pollution. Li et al. (2019) analyzed the relationship between spatial change and urban form for eight pollutants in Shanghai. $PM_{2.5}$ concentrations were higher in the western part of Shanghai and lower in the eastern part. This is because the regional influence of neighboring provinces affected the spatial pattern of $PM_{2.5}$, and PM_{10} showed a relatively high level in the urban area composed of high-rise buildings, an environment that is not well dispersed by the wind. O_3[3], CO, NO, NO_2 and NOx were dynamically balanced with each other by meteorological factors such as insolation, but changes in time and space were largely influenced by local human activity and transport-related emissions.

3.2.2 Population and urban structure

An increase in the number of people, the level of population density, and the compactness of a city are also related to the degree of air pollution. Borck & Schrauth (2021) shows that the higher the population density, the worse the quality of the local atmosphere. They analyzed the impact of population density on air pollutants such as nitrogen oxides, particulate matter, and ozone using population and air pollutant emissions data from German cities for the period 2002-2015. They found that a 1% increase in population density increased NO_2 by 0.25% and PM_{10} by 0.08%. For O_3, it can be seen that the denser the city, the lower the concentration, and the elasticity is -0.14. Air quality, as measured by the total AQI, decreases with population density, and has an elasticity of 0.14.

There are also research results showing that the concentration and dispersion of the population, along with the population density, affects air pollution. For example, Glaeser & Kahn (2008) confirmed that the spatial distribution of the population is an important determinant of greenhouse gas generation and insisted on the introduction of policies such as carbon tax. This study analyzes four major greenhouse gas emission sources in 66 metropolitan areas in the United States: private within-city transport, public transportation, residential heating (natural gas and fuel oil), and residential electricity

3) Ozone

consumption. Along with keeping population and income constant, it was concluded that the spatial distribution of the population is an important determinant of greenhouse gas emissions as well. Household greenhouse gas production would be lower if urban populations lived at higher population density levels closer to urban centers in countries with warmer winters and cooler summers in areas that use less coal for electricity generation.

Borrego et al. (2006) focused on the structure and form of the city and provided evidence that the shape of the city and the distribution of land use influence urban air quality by determining the location of the emission source and the urban traffic pattern. This paper classified the urban structure into three categories: Corridor City[4], Disperse City[5], and Compact City[6], and analyzed the correlation between air pollutant emissions and air pollution levels for each city. Corridor City has the highest emissions, while Disperse City has the lowest emissions per area, and Compact City features the lowest emissions per resident. It suggests that compact cities with mixed land use have better air quality.

Along with this, there is an empirical analysis of how the type of city affects the concentration of air pollutants. For example, He et al. (2019) analyzed the effect of urban morphology on $PM_{2.5}$ and NO2 concentrations in 10 prefecture-level cities of the Yangtze River Basin from 2000 to 2013. It has been shown that socioeconomic, transport, and urban form factors play a key role in mitigating increases in $PM_{2.5}$ and NO_2. The proximity index (PI), which indicates the density of cities, is significantly negatively correlated with $PM_{2.5}$ and NO_2. Conversely, a significant positive relationship was observed

4) Corridor City is characterized by a growth of linear corridors originating in the city center backed by high-quality transport infrastructure.

5) Disperse City is characterized by low densities, large area requirements, and segregation into distinct zones for residential, commercial, or industrial use, resulting in a high reliance on automobile use.

6) Compact City has high density, mixed land uses, and close proximity to complementary functions (residential, shopping, office) reducing travel time and frequency of travel.

between $PM_{2.5}$ and NO_2 concentrations and the open index (OI) indicating urban fragmentation. Thus, this study suggested that local air pollution concentrations could be mitigated by strengthening urban connectivity, weakening vehicle dependence, and promoting the use of bicycles and walking.

3.3 Summary of Literature Review

The results of the literature review are summarized as follows. First, the characteristics of cities are closely related to air pollution. Urban elements such as urban composition, density, and dispersion of the population, and human activity generate air pollutants and also aggravate/mitigate them, thereby affecting the city's air quality. Second, factors such as traffic and population density have a direct influence on the generation of air pollutants. An increase in traffic volume and concentration of population may exacerbate air pollution, and the two factors may synergize and make the air worse. This is the result confirmed through case analysis in Europe and China. Based on this, the papers suggest policies such as the expansion of eco-friendly transportation methods such as bicycles and walking and the strengthening of connectivity between cities. By referring to the important meanings identified through the literature review, variables necessary for the study were selected and hypotheses were established as follows.

Chapter 4. Methodology

4.1 Hypothesis and Variables

This study analyzes how many urban characteristics are related to air pollution and intends to suggest policy implications for air quality management based on these results. For this purpose, the research method is to derive correlation at a significant level by performing correlation analysis and multiple regression analysis, which is consistent with the purpose of the study. Looking at previous studies, there are many examples of using this methodology. A study that analyzed the relationship between local air pollution and urban structure in European cities (Clark et al., 2011) and a study that analyzed the tendency relationship between air pollutants and urban form features (Li et al., 2019) also conducted a correlation analysis, which drew reasonable conclusions. Therefore, correlation analysis and multiple regression analysis are performed to analyze the relationship between urban characteristics and air pollutants in this study.

Research Question : The research question is ‘what elements of the city are closely related to the number of substances such as NO_2, CO, SO_2, PM10, and PM2.5 in the air that cause climate change and air pollution?’

Hypothesis : The hypothesis for the study is as follows.

(H1) Densities of population, automobile, road, and industry are positively related to the concentration of CO, NO_2, SO_2, PM10, and PM2.5 in the air.

Variables : Since the purpose of this study is to understand how urban characteristic variables affect the concentration of air pollutants, independent and dependent variables were composed as shown in Table 1. The amount of NO_2, CO, SO_2, PM10, and PM2.5 generated in cities was set as dependent variables. This is because NO_2, CO, SO_2 are both air pollutants and climate change triggers, and PM10 and PM2.5 are fine dust.

Table 3. Variables

Variables	
DV	The concentration of NO_2, CO, SO_2, PM_{10}, and $PM_{2.5}$ in the air
IV	**(IV 1) Demographic Factors**

	(1-1) Number of Population	(Total City Population)
	(1-2) Population Density	(Total City Population / City Area)
	(IV 2) Transportation Factors	
	(2-1) Transportation Density	(Vehicle Registration Number / City Area)
	(2-2) Road Density	(Road length / City Area)
	(IV 3) Land Use Factors	
	(3-1) Density of Land for Green Space	(Green Space / City Area)
	(3-2) Density of Land for Agriculture	(Agricultural Space / City Area)
	(IV 4) Industrial Factors	
	(4-1) Density of Food and Beverage Manufacturers	(Total Number of Food and Beverage Manufacturers / City Area)
	(4-2) Density of Textile, apparel, leather manufacturers	(Total Number of Textile, apparel, leather manufacturers / City Area)
	(4-3) Density of Wood, Furniture, Paper Manufacturers	(Total Number of Wood, Furniture, Paper Manufacturers / City Area)
	(4-4) Density of Petrochemical Manufacturers	(Total Number of Petrochemical Manufacturers / City Area)
	(4-5) Density of Steelmaking and Metal processing Manufacturers	(Total Number of Steelmaking and Metal processing Manufacturers / City Area)
	(4-6) Density of Automobile and Transportation equipment Manufacturers	(Total Number of Automobile and Transportation equipment Manufacturers / City Area)
	(4-7) Density of Electronic, Electrical, Mechanical Manufacturers	(Total Number of Electronic, Electrical, Mechanical Manufacturers / City Area)
	(4-8) Density of Medical substances and Pharmaceuticals Manufacturers	(Total Number of Medical substances and Pharmaceuticals Manufacturers / City Area)
	(4-9) Density of Printing and Recording media duplication Manufacturers	(Total Number of Printing and Recording media duplication Manufacturers / City Area)
	(4-10) Density of Rubber and Plastics Manufacturers	(Total Number of Rubber and Plastics Manufacturers / City Area)

Independent variables were set as demographic characteristics, transportation characteristics, land characteristics, and industrial characteristics as the components of cities required for correlation analysis.

Among population characteristics, population density is a very important variable because it plays a strong role as a source of air pollution. Therefore, the population density along with the number of the population will be analyzed to determine whether there is a correlation.

As seen in the literature review, traffic characteristics are important variables that directly affect air pollution. However, the size of vehicle registrations does not represent road traffic. Therefore, traffic characteristics will be analyzed by dividing them into transportation sources and road sources.

To evaluate how much air pollutants are emitted depending on the land used for each purpose such as green space, agriculture, the land characteristics will be analyzed relative to the population of land by use.

Lastly, the characteristics of the industry, one of the sectors with the highest contribution to air pollution, are classified and set as an independent variable. This was reclassified based on the industrial classification of Korea Urban Statistics (2020), and the density using the urban area was set as an independent variable.

4.2 Data Collection and Analysis

The air pollution measurement data by city, which is a dependent variable, was used by the National Institute of Environmental Research's latest Air Environment Annual Report (2019). For the emission data by air pollutants, the National Air Pollutants Emission (2020) published by the National Academy of Environmental Sciences was used. In addition, urban characteristics as independent variables were reprocessed and used according to the purpose of analysis based on Korea Urban Statistics (2020) published by the Ministry of the interior and safety.

Table 4. Concentrations of Air Pollutants

	NO_2 (ppm)	SO_2 (ppm)	CO (ppm)	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)
Seoul	0.028	0.004	0.5	42	25
Busan	0.019	0.005	0.4	36	29
Taegu	0.019	0.003	0.5	39	27
Incheon	0.024	0.005	0.5	43	31
Kwangju	0.018	0.003	0.4	42	23
Daejon	0.019	0.002	0.4	42	23
Ulsan	0.020	0.005	0.5	37	22
Sejong	0.019	0.003	0.5	44	28
Suwon	0.028	0.003	0.6	42	28
Seongnam	0.029	0.003	0.6	43	24
Uijungbu	0.025	0.004	0.6	43	19
Anyang	0.030	0.003	0.5	48	24
Bucheon	0.028	0.005	0.5	55	21
Kwangmyung	0.032	0.003	0.5	48	25
Pyungteak	0.021	0.005	0.4	53	17
Ansan	0.027	0.004	0.5	45	24

Koyang	0.020	0.004	0.5	45	20
Guri	0.024	0.003	0.4	45	18
Namyangju	0.022	0.003	0.5	43	20
Osan	0.028	0.003	0.5	45	16
Siheung	0.029	0.004	0.5	53	24
Kunpo	0.027	0.004	0.5	50	20
Hanam	0.030	0.003	0.5	45	16
Youngin	0.024	0.003	0.5	41	26
Paju	0.021	0.003	0.5	49	16
Icheon	0.017	0.004	0.5	45	16
Kimpo	0.017	0.003	0.4	47	22
Whaseong	0.018	0.005	0.5	48	21
Kwangju	0.027	0.004	0.5	48	24
Yangju	0.017	0.003	0.4	44	15
Chuncheun	0.016	0.003	0.5	43	19
Wonju	0.017	0.003	0.5	44	-
Kangneung	0.012	0.002	0.3	36	24
Cheongju	0.021	0.003	0.4	45	18
Chungju	0.022	0.004	0.5	45	15
Cheonan	0.023	0.004	0.6	47	16
Asan	0.016	0.004	0.4	52	31
Jeonju	0.017	0.004	0.4	47	29
Kunsan	0.012	0.004	0.5	46	27
Iksan	0.015	0.003	0.4	49	31
Mockpo	0.010	0.003	0.5	40	20
Yeosu	0.013	0.005	0.5	32	18
Sunchun	0.012	0.004	0.5	32	18
Pohang	0.015	0.004	0.5	38	19
Kyungju	0.013	0.004	0.4	36	20
Kumi	0.016	0.003	0.4	48	20
Kyungsan	0.010	0.004	0.4	42	24

Changwon	0.020	0.004	0.5	40	19
Jinju	0.014	0.003	0.5	39	17
Kimhae	0.019	0.004	0.4	39	21
Keoje	0.016	0.003	0.5	35	19
Yangsan	0.020	0.004	0.5	41	21
Cheju	0.013	0.003	0.3	39	21

In this study, sampling was performed to select cities to be analyzed. Currently, Korea's urban air monitoring network has installed and is operating 495 stations in 161 cities. Cities to be analyzed must have such a monitoring station built and operated. In addition, based on the fact that air pollution has a close influence on human activities, 52 cities with a population of 200,000 or more were analyzed.

Table 5. Characteristics of Cities

	Number of Population	Population Density	Land for Agriculture	Land for Green Space	Food and Beverage	Textile, apparel, leather	Wood, Furniture, Paper	Petrochemical
Seoul	9,765,623	16,135	0.583	25.587	0.210	2.776	0.198	0.117
Busan	,441,453	4,470	7.245	45.959	0.407	0.818	0.160	0.087
Taegu	2,461,769	2,786	8.671	55.126	0.158	0.745	0.141	0.050
Incheon	2,954,642	2,843	16.399	37.599	1.921	1.149	1.475	0.609
Kwangju	1,459,336	2,912	18.610	38.398	0.152	0.076	0.070	0.038
Daejon	1,489,936	2,762	7.032	55.471	0.159	0.109	0.067	0.113
Ulsan	1,155,623	1,089	9.481	64.690	0.038	0.086	0.037	0.176
Sejong	314,126	465	11.225	36.847	0.054	0.003	0.029	0.045
Suwon	1,201,166	9,923	8.550	21.793	0.198	0.083	0.099	0.074
Seongnam	954,347	6,738	2.902	50.134	0.607	0.522	0.071	0.184
Uijungbu	447,026	5,482	3.422	58.928	0.368	0.699	0.135	0.196

Anyang	576,831	9,867	1.078	51.403	0.086	0.753	0.017	0.086
Bucheon	843,768	15,789	10.011	18.769	1.085	1.740	0.524	0.749
Kwangmung	326,841	8,483	11.498	38.723	0.234	0.415	0.052	0.078
Pyungteak	495,642	1,082	39.670	18.031	0.146	0.037	0.133	0.229
Ansan	660,343	4,243	12.574	40.652	0.347	0.919	0.662	0.893
Koyang	1,044,189	3,895	13.604	35.415	0.220	0.175	0.358	0.041
Guri	203,553	6,109	9.004	39.976	0.390	0.480	0.150	0.000
Namyangju	681,828	1,488	5.844	68.118	0.153	0.135	0.229	0.011
Osan	220,070	5,151	10.089	26.568	0.234	0.094	0.187	0.538
Siheung	448,687	3,236	17.815	30.934	0.144	0.296	0.469	0.765
Kunpo	276,916	7,603	5.107	45.991	0.824	0.522	0.384	0.357
Hanam	254,415	2,736	2.979	52.694	0.204	0.398	0.258	0.054
Youngin	1,035,126	1,751	11.957	51.306	0.152	0.036	0.193	0.046
Paju	451,848	671	15.728	40.386	0.134	0.058	0.408	0.073
Icheon	214,206	464	35.830	37.282	0.193	0.037	0.106	0.033
Kimpo	423,170	1,530	26.114	25.304	0.246	0.116	1.070	0.296
Whaseong	758,722	1,093	30.627	27.281	0.171	0.066	0.339	0.265
Kwangju	363,782	844	6.471	66.002	0.248	0.183	0.492	0.072
Yangju	216,951	699	12.502	52.610	0.209	0.983	0.174	0.084
Chuncheun	280,640	251	8.876	73.229	0.030	0.003	0.004	0.008
Wonju	344,070	396	13.548	70.318	0.061	0.006	0.012	0.017
Kangneung	212,957	205	9.802	79.710	0.044	0.001	0.002	0.004
Cheongju	837,749	890	18.000	50.908	0.099	0.039	0.078	0.067
Chungju	210,504	214	13.977	62.861	0.060	0.006	0.026	0.025
Cheonan	646,075	1,047	20.569	51.300	1.072	0.321	0.445	0.346
Asan	312,822	576	27.257	34.796	0.623	0.146	0.313	0.203
Jeonju	651,091	3,198	24.180	30.323	0.112	0.296	0.097	0.068
Kunsan	272,645	702	35.694	20.337	0.103	0.018	0.106	0.098
Iksan	294,062	591	45.957	23.763	0.158	0.118	0.034	0.067

Mockpo	232,327	4,500	9.936	22.448	0.252	0.097	0.019	0.000
Yeosu	283,300	555	14.505	60.001	0.108	0.010	0.008	0.157
Sunchun	279,389	307	14.156	68.767	0.018	0.003	0.003	0.015
Pohang	510,013	451	11.667	66.552	0.033	0.004	0.012	0.024
Kyungju	256,864	194	14.631	67.385	0.018	0.020	0.014	0.020
Kumi	421,494	685	18.175	55.521	0.018	0.135	0.044	0.078
Kyungsan	261,093	634	23.225	56.314	0.104	0.221	0.085	0.092
Changwon	1,053,601	1,409	3.301	56.977	1.352	0.380	0.440	0.118
Jinju	345,987	485	13.248	59.202	0.692	0.272	0.199	0.066
Kimhae	533,672	1,152	15.530	51.449	1.213	0.788	1.310	0.760
Keoje	250,516	622	32.899	70.565	0.412	0.065	0.109	0.017
Yangsan	348,639	718	8.139	74.642	0.770	0.426	0.628	0.408
Cheju	485,946	497	30.314	45.718	0.073	0.001	0.006	0.009

	Steel making, Metal processing	Automobile, Transportation equipment	Electronic, Electrical, Mechanical	Medical substances and Pharmaceuticals	Printing and Recording media duplication	Rubber and Plastics	Transportation	Road
Seoul	0.245	0.036	1.356	0.048	0.618	0.132	5162.673	13725.924
Busan	1.236	0.499	1.403	0.019	0.066	0.407	1780.882	4395.926
Taegu	0.901	0.340	0.809	0.012	0.054	0.298	1333.703	3272.112
Incheon	6.047	0.653	7.969	0.049	0.540	1.446	1483.731	3286.110
Kwangju	0.515	0.319	0.856	0.006	0.034	0.299	1325.530	3723.934
Daejon	0.126	0.089	0.532	0.041	0.041	0.076	1241.746	3969.518
Ulsan	0.317	0.615	0.276	0.004	0.001	0.072	525.751	2058.917
Sejong	0.050	0.044	0.077	0.015	0.016	0.054	215.458	587.121
Suwon	0.215	0.190	2.734	0.041	0.083	0.339	4171.367	7858.306
Seongnam	0.092	0.021	2.175	0.127	0.049	0.099	2402.648	4665.080

Uijungbu	0.392	0.147	4.341	0.098	0.074	0.564	1905.273	5687.712
Anyang	0.051	0.000	0.239	0.000	0.000	0.154	3615.737	6360.383
Bucheon	4.622	0.393	12.163	0.075	0.674	3.892	5760.816	11413.192
Kwangmung	0.363	0.104	2.102	0.000	0.052	0.234	2822.580	6709.162
Pyungteak	0.432	0.207	0.709	0.024	0.020	0.332	565.199	1779.413
Ansan	3.759	0.765	6.566	0.186	0.270	1.054	1913.711	5779.928
Koyang	0.168	0.022	0.444	0.026	0.489	0.160	1515.551	3013.996
Guri	0.210	0.030	0.150	0.060	0.060	0.060	2186.915	5038.205
Namyangju	0.240	0.026	0.196	0.009	0.002	0.151	609.358	805.772
Osan	0.655	0.164	1.615	0.070	0.000	0.304	2335.159	3781.227
Siheung	3.310	0.894	5.005	0.101	0.065	1.067	1588.554	4886.585
Kunpo	1.702	0.165	8.210	0.137	0.302	2.526	2769.495	5590.857
Hanam	0.194	0.043	0.312	0.022	0.043	0.226	1124.228	1013.227
Youngin	0.122	0.037	0.457	0.034	0.019	0.171	764.349	731.392
Paju	0.307	0.013	0.330	0.010	0.235	0.244	309.276	792.404
Icheon	0.150	0.030	0.238	0.004	0.004	0.130	241.730	898.877
Kimpo	1.985	0.108	1.591	0.029	0.076	0.904	726.681	895.600
Whaseong	1.385	0.474	1.951	0.085	0.037	0.909	565.748	1127.819
Kwangju	0.434	0.028	0.485	0.012	0.035	0.441	428.994	870.199
Yangju	0.367	0.013	0.348	0.010	0.006	0.409	321.006	1407.853
Chuncheun	0.011	0.001	0.021	0.010	0.003	0.004	117.883	798.825
Wonju	0.036	0.045	0.068	0.014	0.000	0.028	191.317	1365.554
Kangneung	0.002	0.000	0.012	0.002	0.001	0.006	102.746	942.914
Cheongju	0.108	0.051	0.347	0.029	0.012	0.117	431.533	1707.059
Chungju	0.092	0.040	0.058	0.009	0.000	0.037	109.896	1176.684
Cheonan	1.413	0.445	3.069	0.041	0.201	0.604	496.650	1383.918
Asan	0.921	0.792	1.982	0.028	0.053	0.523	299.267	1343.564
Jeonju	0.058	0.029	0.223	0.015	0.024	0.039	1530.901	4639.961
Kunsan	0.293	0.108	0.159	0.003	0.000	0.040	334.945	2504.766

Iksan	0.069	0.116	0.109	0.010	0.004	0.049	278.915	1842.119
Mockpo	0.039	0.329	0.097	0.000	0.000	0.019	1932.597	9228.549
Yeosu	0.070	0.037	0.057	0.004	0.002	0.012	257.267	1893.355
Sunchun	0.078	0.008	0.022	0.000	0.001	0.009	149.009	1215.691
Pohang	0.178	0.014	0.092	0.000	0.001	0.009	231.973	1182.159
Kyungju	0.123	0.249	0.111	0.000	0.000	0.046	106.484	789.419
Kumi	0.213	0.057	0.770	0.003	0.005	0.179	345.276	922.368
Kyungsan	0.291	0.289	0.284	0.007	0.005	0.177	330.007	2291.894
Changwon	3.895	1.183	4.593	0.009	0.468	0.262	748.970	2614.909
Jinju	0.485	0.341	1.206	0.001	0.084	0.052	229.551	1419.685
Kimhae	6.480	1.953	5.899	0.011	0.224	2.039	570.317	2849.578
Keoje	0.206	0.732	0.139	0.000	0.020	0.015	261.399	1762.205
Yangsan	1.917	0.550	1.798	0.025	0.082	1.328	341.336	1619.128
Cheju	0.003	0.000	0.012	0.001	0.002	0.007	459.856	2278.732

The SPSS program was used to analyze the data and test hypotheses. First, Pearson correlation analysis was used to reveal the correlation between urban characteristic variables and air pollutants. A two-tailed test was performed to confirm the statistical significance of this analysis. Second, linear regression analysis was used to infer a causal relationship between urban characteristics as an independent variable and air pollution by a substance as a dependent variable. The significance of the regression analysis is verified by the F-value and the significance probability of the ANOVA analysis, and tolerance and VIF (Variance Inflation Factor) are reviewed and evaluated to check the multicollinearity problem. Through this, urban characteristics that have a close influence on air pollution can be identified for each category, and policy proposals for air quality improvement can be made by analyzing these characteristics.

4.3 Limitations of the Methodology

Since air pollution is a phenomenon that occurs in combination with various factors, particularly climate factors such as wind and temperature, it is difficult to analyze the direct correlation with urban characteristics. However, rather than setting the number of air pollutants generated from urban sources as the dependent variable, the analysis was conducted assuming that climatic factors were already included by setting the air pollution measurement value as the dependent variable.

Chapter 5. Results

5.1 Correlation Analysis

Correlation analysis was conducted to find out whether there was a correlation between urban characteristic variables and air pollution by each pollutant. Table 2 shows the correlations between urban characteristics and air pollution by each pollutant.

5.1.1 Nitrogen Dioxide

NO_2 correlated closely with all categories of independent variables. First, as a result of correlation analysis between NO_2 and urban characteristic variables, NO_2 has the highest positive correlation with Transportation Density (r (52) = .657). Then, followed by Population Density (r (52) = .647, p⟨.01), Density of Medical substances and Pharmaceuticals Manufacturers (r (52) = .555, p⟨.01), Land for Agriculture (r (52) = −.470, p⟨.01), and Density of Electronic, Electrical, Mechanical Manufacturers (r (52) = .459, p⟨.01) showed a high correlation.

5.1.2 Carbon Monoxide

In the correlation analysis for CO, Land for Agriculture (r (52) = .356, p⟨.01) showed the highest positive correlation, and Density of Medical substances and Pharmaceuticals Manufacturers (r (52) = .334), p⟨.01), and Transportation Density (r (52) = .300, p⟨.01) showed a high correlation in the order, but overall, the correlation with urban characteristics is low.

5.1.3 Sulfur Dioxide

Also, for SO_2, a strong correlation was formed with the industrial factor among the categories of independent variables. Density of Steelmaking and Metal processing Manufacturers (r (52) = .420, p⟨.01), Density of Petrochemical Manufacturers (r (52) = .408, p⟨.01), Density of Electronic, Electrical, Mechanical Manufacturers (r (52) = .407, p⟨.01), and Density of Rubber and Plastics Manufacturers (r (52) = .406, p⟨.01) showed a high positive correlation in the order.

5.1.4 Particulate Matter 10

As a result of correlation analysis with urban characteristics of PM_{10}, it had the highest negative correlation with Land for Green Space ($r\ (52) = -.573$, $p<.01$), and Density of Rubber and Plastics Manufacturers ($r\ (52) = .402$, $p<.01$), and Density of Medical substances and Pharmaceuticals Manufacturers ($r\ (52) = .360$, $p<.01$) were found to have a high positive correlation.

5.1.5 Particulate Matter 2.5

In the case of $PM_{2.5}$, overall, the relationship with urban characteristics was not close. Number of Population ($r\ (52) = .306$, $p<.01$) and Land for Green Space ($r\ (52) = -.303$, $p<.01$) were analyzed to show high correlation. However, in this study, as far as PM_{10} and $PM_{2.5}$ are concerned, Land for Green Space was recognized as an important factor with a high correlation.

Table 6. Pearson Correlations between Elements of City and Air Pollutant

Independent Variables		NO_2	CO	SO_2	PM_{10}	$PM_{2.5}$
(IV 1) Demographic Factors	(1-1) Number of Population	.234	.065	.175	-.123	**.306***
	(1-2) Population Density	**.647****	.299*	.077	.279*	.193
(IV 2) Transportation Factors	(2-1) Transportation Density	**.657****	**.300***	.081	.292*	.221
	(2-2) Road Density	.459**	.228	.108	.179	.235

(IV 3) Land Use Factors	(3-1) Land for Green Space	-.231	-.007	-.186	**-.573****	**-.303***
	(3-2) Land for Agriculture	**-.470****	**-.356****	.155	.230	.098
(IV 4) Industrial Factors	(4-1) Density of Food and Beverage Manufacturers	.240	.209	.337*	.096	.091
	(4-2) Density of Textile, apparel, leather manufacturers	.448**	.135	.260	.133	.182
	(4-3) Density of Wood, Furniture, Paper Manufacturers	.243	.049	.312*	.203	.130
	(4-4) Density of Petrochemical Manufacturers	.404**	.147	**.408****	.336*	.089
	(4-5) Density of Steelmaking and Metal processing Manufacturers	.247	.047	**.420****	.164	.151
	(4-6) Density of Automobile and Transportation equipment Manufacturers	.023	.007	.348*	-.064	.130
	(4-7) Density of Electronic, Electrical, Mechanical Manufacturers	**.459****	.248	**.407****	.351*	.125
	(4-8) Density of Medical substances and Pharmaceuticals Manufacturers	**.555****	**.334***	.180	**.360****	.067
	(4-9) Density of Printing and Recording media duplication Manufacturers	.363**	.214	.365**	.214	.082
	(4-10) Density of Rubber and Plastics Manufacturers	.351*	.097	**.406****	**.402****	.046

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

5.2 Regression Analysis

In this study, a regression analysis was performed on highly correlated and statistically significant variables based on the results of correlation analysis between air pollutants and urban characteristic variables. The regression analysis results for CO, SO_2, $PM_{2.5}$ had little explanatory power, but the analysis results for NO_2, PM_{10} are as follows.

5.2.1 Model 1 : Nitrogen Dioxide

As a result of estimating the regression model between NO_2 and urban characteristic variables, the F-value was statistically significant as 7.565 ($p<.001$). The coefficient of determination (adjusted R^2), meaning the explanatory power of the estimated regression analysis model, was .669, which means it has an explanatory power of 66.9%. Road Density ($t=-4.384$, $p<.01$), Density of Rubber and Plastics Manufacturers ($t=-2.403$, $p<.05$), and Density of Land for Agriculture ($t=-1.752$, $p<.1$) were adopted as variables that have a great influence on the concentration of NO_2. Based on the standardized coefficient indicating the influence of the variable, among the three independent variables, Road Density ($\beta=-1.132$), Density of Rubber and Plastics Manufacturers ($\beta=-0.568$), and Density of Land for Agriculture ($\beta=-0.249$) were analyzed as influencing NO_2 concentration.

Table 7. Regression analysis result of Model 1.

Independent Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
(Constant)	0.023	0.005		4.903	.000***		
Density of Land for Agriculture	0.000	0.000	-0.249	-1.752	.088*	0.315	3.171
Density of Rubber and Plastics Manufacturers	-0.005	0.002	-0.568	-2.403	.022**	0.114	8.769

*p〈.1. **p〈0.5, ***p〈.01, N=52, F=7.565 (p〈.001), Adj. R^2 = .669

5.2.2 Model 2 : Particulate Matter 10

In the PM_{10} regression model, the F-value was 3.313, which was statistically significant (p=.001), and the coefficient of determination (adjusted R^2) was .416, which has an explanatory power of 41.6%. A number of the population (t=−1.725, p=.093) and Density of Land for Green Space (t=−3.197, p=.003) were adopted as variables that had a great influence on PM_{10} concentration. Among them, it was analyzed that the Density of Land for Green Space (β=−0.671) and the Number of Population (β=−0.380) affect the PM_{10} concentration in order.

Table 8. Regression analysis result of Model 2.

Independent Variables	Unstandardized Coefficients	Standardized Coefficients	t	Sig.	Collinearity Statistics

	B	Std. Error	Beta			Toler ance	VIF
(Constant)	55.500	5.434		10.213	.000***		
Number of Population	0.000	0.000	-0.380	-1.725	.093*	0.231	4.328
Density of Land for Green Space	-0.205	0.064	-0.671	-3.197	.003***	0.255	3.918

*p〈.1. **p〈0.5, ***p〈.01, N=52, F=3.313 (p=.001), Adj. R^2 = .416

5.2.3 Model 3 : Carbon Monoxide

As a result of estimating the regression model of Carbon Monoxide, the coefficient of crystal (R^2), which means the explanatory power of the model, was 0.113, showing an explanatory power of 11.3%, and was generally low. Although the explanatory power of this model is somewhat poor, this model will be introduced to explain the variables that show the influence related to the formation of carbon monoxide in this study.

In the regression model of Carbon Monoxide, the Density of Land for Green Space variable was adopted as the Land Use Factor. The significance probability of the variable is 0.096, which holds a statistical significance of 10%. The Beta value representing the influence of the variable is -0.661, indicating the concentration of carbon monoxide and the negative influence.

Table 9. Regression analysis result of Model 3.

Independent Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	

	B	Std. Error	Beta			Toler ance	VIF
(Constant)	0.502	0.087		5.793	.000***		
Density of Land for Green Space	-0.062	0.036	-0.661	-1.709	.096*	0.114	8.769

*p<.1. **p<0.5, ***p<.01, N=52, F=1.412 (p=.191), Adj. R^2 = .113

5.2.4 Model 4 : Particulate Matter 2.5

As a result of estimating the regression model of Particulate Matter 2.5, the coefficient of determination (R^2), which means the explanatory power of the model, was 0.038, showing an explanatory power of 3.8%, and was generally low. Although the explanatory power of this model is not high, this model will be introduced to explain the variables that show the influence related to the formation of Particulate Matter 2.5.

In the regression model of Particulate Matter 2.5, Number of Population variable as the Demographic factor and the Density of Land for Green Space variable as Land Use factor were adopted. The probability of significance of the variable is that the Number of Population is 0.057, and the density of Land for Green Space is 0.051, so it has a statistical significance of 10%. The Beta value, which represents the influence of the variable, shows a positive influence with Number of Population of 0.562, and a density of Land for Green Space is −0.599, which shows a negative influence.

Table 10. Regression analysis result of Model 4.

Independent Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
(Constant)	55.500	5.434		10.213	.000***		
Number of Population	0.000	0.000	0.562	1.970	.057*	0.231	4.324
Density of Land for Green Space	-15.670	7.764	-0.599	-2.018	.051*	0.214	4.678

*p〈.1. **p〈0.5, ***p〈.01, N=52, F=1.128 (p=.369), Adj. R^2 = .038

Chapter 6. Discussion and Recommendations

6.1 Findings

6.1.1 Nitrogen Dioxide

NO_2 showed a relatively high correlation in all areas of the independent variables. NO_2 is mainly generated in the combustion process of fossil fuels such as diesel and gasoline, and in the process of manufacturing chemical substances. In this correlation analysis, the highest number was shown in Transportation Density, and diesel vehicles such as trucks and construction machinery are presumed to be the main cause. This is also the basis for explaining the tendency of NO_2 pollution in the metropolitan area where mobile pollution sources are concentrated. In addition, the correlation with industrial activities such as Electronic, Electrical, and Mechanical Manufacture as well as Medical substances and Pharmaceuticals Manufacture was high, suggesting that NO_2 generated in industrial processes has a great influence on the atmospheric concentration of NO_2. Conversely, the pollution level of NO_2 and the land for agriculture relative to the population showed a negative correlation, which means that the higher the NO_2 is, the smaller the arable area per capita. Therefore, the NO_2 reduction effect can be obtained if the per capita arable area is expanded such as urban agriculture.

6.1.2 Carbon Monoxide

CO is mainly generated when fuels such as coal and oil are burned, from road transport pollutants such as automobiles, commercial facilities, and manufacturing industries. Since Korea's CO pollution level is generally low and there is little regional difference, the correlation with urban characteristic variables was also low, and a suitable regression model could not be derived. However, in this analysis, a high correlation with Transportation Density was confirmed, which provides an important clue to the policy for the expansion of alternative means of transportation as well as the regulation for air pollution reduction in the transportation sector. In addition, the relation between CO pollution and Land for Agriculture showed a negative correlation. In this regard, since the expansion of arable land also helps to reduce CO, policies that develop this can be effective.

6.1.3 Sulfur Dioxide

SO_2 is generated from the combustion of fuels such as coal and petroleum containing sulfur, metal smelting, and industrial processes. Despite the recent increase in the number of registered vehicles and the increase in fuel consumption in Korea, the concentration of SO_2 in the atmosphere is decreasing, which is believed to be attributable to the government’s continued fuel policy, including the expansion of low-sulfur oil and LNG supply, and strengthening of emission regulations. For this reason, the results of the correlation analysis between SO_2 and urban characteristics conducted in this study showed little association. Therefore, the regression analysis could not derive a meaningful regression model either. However, results from the correlation with industrial sectors such as steelmaking, smelting, and petrochemicals suggest implications for setting policy directions for SO_2 reduction.

6.1.4 Particulate Matter 10 and 2.5

Fine dust is emitted directly from the emission source or is secondarily generated by gaseous substances such as SOx[7] and NOx, and the main emission sources are automobile exhaust gas and industrial facilities such as chemical and oil refineries. As indirect emissions from secondary generation account for about 72% of the total emission in Korea (Ministry of Environment et al., 2017), it is difficult to directly determine the correlation with a single variable, but in this correlation analysis, the industrial factor Rubber and

7) compounds of sulfur and oxygen molecules

Plastics Manufacture and Medical substances and Pharmaceuticals Manufacture were found to be highly related. Particular attention should be paid to the point regarding fine dust and its relevance to Land for Green Space. This can be shown not only in PM_{10} but also in $PM_{2.5}$, which formed a high negative correlation with green space. This means that fine dust can be reduced as the density of greenery increases, because other independent variables have a positive correlation with pollution sources, whereas green spaces have an effect of reducing pollution. This result shows that to solve the fine dust problem in Korea, it is necessary to consider policies other than reducing fine dust generation through emission source regulation.

6.2 Limitations

In air pollution, it is not easy to determine a direct correlation with specific factors because diverse weather conditions overlap, and many pollutants interact. The average annual concentration of air pollutants varies depending on factors that inhibit the diffusion of substances into the atmosphere, such as physical features of an area and the density and height of buildings, as well as variable meteorological factors such as rainfall, wind direction, and wind speed. This is also the reason why explanatory regression models were not derived relatively easily in this study.

In the case of SO_2, it is presumed that the regression model with city characteristic variables cannot be made because the pollution level stays low due to the environmental standard achievement rate is high. In addition, it is presumed that PM2.5 is largely affected by weather factors such as wind speed and rainfall, but is not reflected.

To find a more precise correlation, it is also worth considering a method to further subdivide the classification of independent variables and to analyze them by classifying cities with dense industrial facilities, cities with high traffic volume, etc.

Chapter 7. Recommendations

6.1 The Current State and Policies

Concentrations of SO_2 and PM10 are continuously decreasing due to the government's air quality improvement policies such as the use of low-sulfur fuel, expansion of supply of clean fuels such as LNG, and strengthening of emission regulations. However, the increase in temperature and the continuous increase in the number of registered vehicles due to climate change do not effectively reduce pollutants such as NO_2. In addition, in the case of fine dust, which is the most controversial air pollution in Korea, conditions such as climate, topographical conditions, and rainfall are not favorable for improvement. Geographically located in the westerly wind region, Korea is affected by menstrual pollutants from neighboring countries, and rainfall is concentrated in summer, so cleaning effects are rare in winter and spring, and air congestion is intensifying, so high-concentration fine dust is often generated in Korea. Under these circumstances, Korea's world-wide high population density, vehicle concentration, and manufacturing-oriented industrialization factors combine to make the problem more and more aggravated.

In the meantime, the Ministry of Environment is promoting policies such as subdivision and expansion of air pollutants, establishment and reinforcement of emission standards, and measures to improve air quality in the metropolitan area (November 2005-). In addition, in order to prevent or reduce damage to the air environment due to the emission of air pollutants, an air polution emission charge system is in operation that imposes an economic burden on business operators equivalent to air pollutant treatment costs according to the polluter-pays principle. In relation to vehicle fuel, the duty to use low-sulfur oil, the prohibition of the use of solid fuel in areas concerned about exceeding environmental standards, and the duty to use clean fuel are given to boilers for business, apartment houses, district heating facilities and power generation facilities.

In the case of fine dust, “Special measures for fine dust management (2016.6-)” were established and promoted, and in 2017, “Comprehensive measures for fine dust management (2017.9-)”, which set a reduction target that was twice that high, are being promoted. In addition, in 2018, "Emergency and regular fine dust management reinforcement measures (2018.11-)" were established to achieve results at a level perceived by the public, and in 2019, the "Comprehensive Fine Dust Management Plan (2019.11-)" It was established and suggested the policy direction and tasks to deal with fine dust from 2020 to 2024.

6.2 Recommendations

① General suggestions

Based on the findings, three major policy recommendations are made to reduce substances such as NO_2, CO, SO_2, PM_{10}, and $PM_{2.5}$ in the air that cause climate change and air pollution.

First, it is necessary to effectively reduce the number of air pollutants generated in the transportation sector. To this end, diesel vehicles that are aging and emit a lot of pollutants should be reduced. In the case of early scrapping of these vehicles, the subsidy to support the purchase of low-emission vehicles should be increased to dramatically reduce pollution sources in the transportation sector. In addition, in Korea, since the proportion of diesel vehicles is still high at 40% of all vehicles as of September 2021 (Ministry of Land, Infrastructure and Transport, 2021), it is necessary to reduce the demand for diesel vehicles by adjusting the price of gasoline and diesel. At the same time, subsidies to promote the purchase of electric and hydrogen vehicles and benefits such as tax support should be increased to convert pollution sources to eco-friendly vehicles.

Second, according to the correlation analysis conducted in this study, air pollutants showed a high correlation with various sorts of industries such as petrochemical manufacture, steel making, and medical substances manufacture. To reduce air pollutants emitted from the industrial sector, the emission standards regulations should be strengthened, and violations of these rules should be strictly enforced and punished. In Korea, many businesses illegally release air pollutants due to insufficient enforcement activities. In addition, for small and medium-sized businesses with low capital and technology, a policy to support the cost of installing air pollutant emission reduction facilities should also be implemented to effectively reduce air pollutants in the industrial sector.

Third, policies that utilize Land for Green Space and Agriculture, which are negatively correlated with air pollutants, should be considered. The negative correlation suggests that it is undesirable in terms of air pollution for cities to expand or increase traffic and industrial activities. Air quality management policies so far in Korea have focused on reducing air pollutant emissions but promoting policies to maintain or expand forests and arable land must also be considered. In particular, in the case of fine dust, it is difficult to reduce it due to the complicated causes and conditions of its generation. It will be helpful to solve fine dust problems by introducing measures to expand green areas and arable lands in the city, such as urban agriculture and rooftop greening.

② Suggestions by Sector

1) Industry

The industrial sector, excluding the power generation sector, uses the most energy in the country and is the largest source of air pollutants and fine dust emissions. However, strong regulations are needed as there are still cases in which the industry illegally emits air pollutants.

Recently, many illegal cases such as manipulation of TMS emissions, false statements of self-measurement results, and operation of unauthorized facilities have been uncovered. Therefore, it is necessary to strictly enforce compliance with laws and respond strongly to these industries. First of all, it is necessary to correct illegal activities such as illegal emission and manipulation of emissions by strengthening the monitoring of illegal emission of pollutants at workplaces. In addition, it is necessary to increase the efficiency of the crackdown by using drones or scientific equipment, and to increase the effectiveness of the crackdown by introducing a reporting reward system.

In addition, technology and financing for small and medium-sized enterprises with low pollutant management capabilities should be combined. They often lack funds to invest in environmental facilities and lack the technology to operate properly to improve the environment. Therefore, support should be drastically expanded to learn the technology to properly operate emission facilities.

Since large business sites emit the majority of all pollutants, it is necessary to establish and implement a plan to improve the efficiency of pollutant reduction devices and to reduce pollutants, and to establish a monitoring system to confirm this. At the same time, it is necessary to prepare a system for reporting reduction performance and evaluating performance.

2) Transportation

Among the national air pollution emissions, many of CO, NOx, and fine dust are emitted from automobiles. In particular, in the metropolitan area, the proportion of pollutants emitted by automobiles is much higher than the national average. This phenomenon is similar in large cities around the world and reflects the importance of transport sector management in cities.

Currently, stricter emission standards and a vehicle emission rating system are being implemented, and in case of emergency reduction measures for fine dust, operation restrictions for vehicles with level 5 emission have been introduced. However, for more effective results, measures to reduce air pollution and fine dust, such as inducing the early scrapping of old diesel vehicles and installing a smoke reduction device, should be continuously promoted. In addition, the supply of low-emission vehicles such as electric vehicles and hydrogen vehicles should be further expanded, and various policies should be harmoniously promoted to establish an eco-friendly transportation system.

3) Agriculture and Forestry

In order to simultaneously respond to air pollution and climate change, it is necessary to first reduce air pollutants and greenhouse gases. There are already large amounts of these substances in the atmosphere, and now they continue to emit more. Therefore, the reduction of pollutants should be implemented most urgently. However, given the current climate crisis and the seriousness of air pollution, more powerful and innovative measures are needed. In other words, it is necessary to consider not only measures to control pollution sources and reduce emissions, but also policies to expand forests and cultivated land. Excessive urbanization exacerbates adverse environmental conditions due to various human activities and urban characteristics. It is not a city as a source of pollution, but a concept of a city that can mitigate air pollution and climate change together by securing green space.

③ Toward "Net-Zero"

Net zero means reducing the greenhouse gas emissions that cause changes in the global climate as close to zero as possible, and the remaining emissions are reabsorbed from the atmosphere by, for example, oceans and forests, balancing greenhouse gas emissions and absorption. Proven climate studies have argued that temperature increases should be limited to 1.5˚C above pre-industrial levels in order to preserve the planet from climate change. Today, the Earth is already about 1˚C warmer than it was before industrialization, and greenhouse gas emissions continue to increase and accumulate. To keep global warming below 1.5˚C, as agreed by the Paris Agreement, the world must cut greenhouse gas emissions by 45% by 2030 and reach net zero by 2050.

Recently, efforts by the state, businesses, and institutions have been increasing to achieve net greenhouse gas emissions, and are making pledges. More than 70 countries, including the United States and the European Union, have set a net zero target of about 76% of global emissions. More than 1,200 companies have set net-zero science-based targets, with more than 1,000 cities, 1,000 educational institutions, and more than 400 financial institutions participating in Race to Zero, promising strict and immediate action to halve global levels. However, so far, the commitments made by governments are far short of what is actually needed. Current national plans for all 193 parties to the Paris Agreement will increase global greenhouse gas emissions by nearly 14% by 2030 compared to 2010 levels (United Nations, n.d.).

Korea is criticized by the international community as a 'climate villain'. This is because the ranking of carbon dioxide emissions is in the top 10 in the world, and efforts to reduce carbon dioxide emissions fall short of the global level. Among various sources of greenhouse gases and fine dust, coal-fired power generation emits about 9% of all fine dust and about 28% of all greenhouse gases in Korea. As of 2020, the energy production rate of coal-fired power plants in Korea is 35.6%. For rapid economic growth and price stability, the historical route of power generation centered on coal and nuclear power with low fuel costs is still affecting. Although the power production ratio of coal-fired power generation has been steadily decreasing due to the government's efforts to reduce fine dust and the policy to exit old power plants, it still accounts for the highest proportion of all energy production.

In order to solve the fine dust problem and cope with climate change, developed countries are currently pushing for policies to exit coal-fired power plants and expand renewable energy. Germany was a representative country dependent on coal-fired power, but it decided to expel coal-fired power by 2038 after social public debate to cope with climate change and sustainable development. The United Kingdom also decided to close coal-fired power plants by 2024 due to its strong will to respond to climate change and the need for low-carbon energy conversion.

As such, the world is expanding eco-friendly energy that replaces coal-fired power plants while reducing them to respond to climate change and convert them into clean and safe energy. However, South Korea is currently building five new coal-fired power plants and is supporting the construction of coal-fired power plants in developing countries. Coal-fired power plants have low fuel costs, but environmental costs such as damage from fine dust and greenhouse gas emissions, and increased investment costs for eco-friendly facilities are on the rise. Therefore, in order for Korea to effectively respond to climate change while maintaining a sustainable society, it is important to consider converting coal-fired power plants into eco-friendly energy.

Coal-fired power plants emit about 10 times more fine dust on average than LNG power plants, and about 6.6 times more than the latest Coal-fired power plants. In the case of air pollutants harmful to the human body such as mercury and chromium, coal-fired power plants emit tens of times more than LNG power plants, and greenhouse gases emit about 1.7 times more. However, coal-fired power plants are easy to manage as large-scale public facilities and have a large emission reduction effect, so if proper management is promoted, greenhouse gases and air pollutants can be effectively reduced. Until now, the Korean government has abolished aging coal-fired power plants in order to reduce fine dust in the power generation sector, suspended construction of new coal-fired power plants, and made active efforts by converting existing coal-fired power plants into LNG power plants. In addition, during the spring when fine dust occurs at high concentrations, management is underway to stop the operation of coal-fired power plants or reduce the operation rate, and air pollutants such as fine dust, SOx, and NOx have strengthened emission standards for operating power plants.

In October 2020, the President declared net zero in his address to the National Assembly, saying, "We will actively respond to climate change together with the international community and move forward toward the goal of being carbon neutral by 2050." Korea is not alone in declaring net zero. Developed countries are already declaring net zero, China, the world's largest emitter of greenhouse gases, has declared that it will achieve carbon neutrality by 2060, and Japan has also declared that it will achieve net zero by 2050. To achieve carbon neutrality by 2050, Korea has many challenges to overcome. Among them, the effective composition and operation of the national energymix including coal-fired power plants is one of the most important tasks. It is not easy to reduce the number of coal-fired power plants that have been used for base power generation, and there is a risk of disruptions in power supply and demand. In addition, if a power generation source with a high unit price, such as LNG, is switched to a power generation source with a low fuel cost, electricity rates are expected to rise, and a social consensus will be required on this. However, renewable energy, which has recently become the hottest issue in the global energy sector, may be one of the solutions. Renewable energy is a clean energy source that does not have the risk of exhaustion such as solar power and wind power, and the related technology development speed is fast, and accordingly, the power generation cost is very low. Countries around the world are already aggressively investing in renewable energy to respond to climate change, efficiently convert energy, and secure new growth engines. Currently, the proportion of renewable energy generation in Korea is about 6%, which is very low compared to advanced countries. Germany maintains a share of renewable energy generation at about 42% and the UK at about 38%, and Korea is the lowest among OECD countries. If Korea reduces its dependence on coal-fired power plants, which aggravates climate change and air pollution, and effectively composes and operates an energymix with eco-friendly power sources such as renewable energy, Korea will be able to preserve a cleaner and healthier environment in the future. Through this, it will not be impossible for Korea to achieve net zero in the not-too-distant future.

Chapter 8. Conclusion

This study analyzed the relationship between urban characteristic variables to cope with climate change and air pollution at the same time. From the perspective of co-benefit, which simultaneously reduces climate change and air pollution, the scope of research was limited to cities to find more practical measures. The subject of the study used objective measurement data from large cities such as special cities and metropolitan cities equipped with a measurement network and medium cities such as general cities. In addition, statistical analysis such as correlation analysis and regression analysis between the characteristics of the city and air pollutants were conducted to make policy proposals based on evidence, and meaningful results were derived. Correlation analysis and multiple regression analysis were sequentially conducted by setting the urban characteristic variable as an independent variable and setting the concentration of air pollutants and climate change-causing substances as dependent variables.

In this process, this study was confirmed through analysis that several urban characteristics are factors affecting air pollution and climate change.

First, nitrogen dioxide is a substance that has the closest correlation with urban characteristics. In particular, as it is a substance mainly generated during the combustion process of fossil fuels, it was very related to the transportation field and industrial activities. Therefore, if urban planning is established in consideration of the characteristics of these cities in the future, environmental benefits will be more effectively obtained. Land for agriculture also shows a relatively high negative correlation with atmospheric concentration of nitrogen dioxide, which will help solve this problem if we actively consider the expansion of green space as well as the inhibition of nitrogen dioxide generation.

Second, carbon monoxide mainly occurs in the combustion of fossil fuels, especially in the transportation sector. The concentration of carbon monoxide in the atmosphere in Korea was gradually decreasing, but now it is stagnant at a low level, so it is worth considering to continue to implement policies to reduce foreign substances and actively promote agricultural land.

Third, in this study, sulfur dioxide did not show much correlation with urban characteristic variables. Rather than being less relevant to the characteristics of the city, it would be reasonable to interpret that it is no longer accumulated at high concentrations in the atmosphere due to the performance of reduction policies such as low sulfur oil use.

Finally, fine dust is generated either directly from the emission source or indirectly from other pollutants, and it is also generated from abroad and introduced into Korea, which is currently one of the most important atmospheric issues in Korea. Although it is difficult to identify the exact cause of fine dust in various ways, this study confirmed that it is closely related to industrial factors such as Rubber and Plastics Manufacture and Medical substances and Pharmaceuticals Manufacture. (In the case of power generation, such as coal-fired power plants, it is known that the relevance to fine dust is very high, but in this study, comparison and analysis were performed with general characteristics of cities, so it is not specifically mentioned.) Also, in this study, what should be noted is the relationship between the concentration of fine dust and the density of green areas. If the expansion of green areas can dramatically reduce fine dust, it is necessary to pursue a bold policy that goes beyond the existing policies and practices in this regard. It is very difficult to change the characteristics and functions of a city, but if the fine dust problem is really urgent and needs to be solved, the priority of many city policies should be actively pursued by focusing on the fine dust solution. This study can be used as a basis to strongly support this idea, and it is necessary in Korea to boldly and actively promote solutions to the fine dust problem.

Although this study has unavoidable limitations due to the complex characteristics of the atmospheric field, it is meaningful in that it identified the effect of urban characteristics on air pollution and climate change among various factors. The results of this study will be helpful in setting policy directions in terms of air quality management and climate change response in urban planning and change, transportation and industrial composition, and green space creation. As a next step based on this study, if urban characteristics are classified at a more specific level and research including a variety of variables, such as wind direction, speed, and interaction between pollutants in the atmospheric field is conducted, the effectiveness of policies with accurate predictions can be achieved. In particular, with regard to fine dust, more reliable research results can be derived if research on topography is added in addition to meteorological conditions.

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