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Analysis of air quality and health co-benefits regarding electric vehicle promotion coupled with power plant emissions

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A B S T R A C T

Purpose of this study is to discuss the electric vehicle policy's effects on air pollution reduction in Taiwan. Since $PM_{2.5}$ is one of Taiwan's major air-pollution issues, Environmental Protection Administration of Taiwan (TEPA) promoted a policy that the sale of cars powered by fossil fuels would be banned in 2040, which means all the pollutants emitted by petrol-engine vehicles will be reduced. But at the same time the electric vehicles require additional power consumption, therefore, it is important to investigate the effect of air quality and health benefit when mobile emission reduces but power plant emission increases.

To evaluate this clean air policy, Weather Research and Forecasting model (WRF) - Community Multi-scale Air Quality model (CMAQ) and Benefits Mapping and Analysis Program (BenMAP) were applied in scenarios discussion. The location of power plants to generate additional electric power and the seasonal variation were adapted in scenarios for considering the atmospheric transportation effects. The results showed if additional power supply was generated in northern, central, or southern Taiwan, the average annual $PM_{2.5}$ concentration would be reduced by 2.88, 2.90, and 2.92 $\mu g/m^3$, respectively. The associated health benefits would be 43.35 billion, 43.40 billion, and 43.54 billion USD. This evaluation presents adopting electric vehicles would improve the air quality of Taiwan significantly.

The analysis of seasonal scenarios also indicates the location to generate additional electric power is important when adopting electric vehicles policy. The prevailing wind of different season will transport the air pollutant to diverse downwind area. The additional electricity demand generated by northern power plants in summer and autumn but switched to southern power plants in spring and winter would reduce 2.95 $\mu g/m^3$ $PM_{2.5}$ and lead to the best air quality and health benefits across Taiwan among the considered options.

1. Introduction

The automobiles and motorcycles rise substantially in the globe, as well as increased consumption of fossil fuels and people's concern about the environment and ecology, according to a WHO report, in 2012, ambient air pollution has caused more than 3.7 million premature deaths (WHO, 2015). Moreover, as air pollution directly affected human health, the number of premature deaths attributable to ambient air pollution has been increased by more than 4 times, as compared with the 800,000 deaths in 2000. It could be seen that air pollution is increasingly endangering people's lives and has become a growing public health concern in the globe. In addition, particulate matter (PM) have been classified into Primary Carcinogens by the WHO in 2013, as PM containing carcinogens, including mercury, lead, sulfuric acid, benzene and dioxin, are inhalable into trachea and bronchus, and further into blood and various organs of human bodies (IARC, 2013).

Main sources of air pollutants are industry and traffic in Taiwan; however, motorcycles and automobiles rise substantially, it will become a serious problem of air quality. At present, replacing fuel-

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powered motorcycles and automobiles with electric vehicles or vehicles powered by biomass energy is one of the solutions for addressing the air pollution caused by motorcycles and automobiles. Watson et al. (2001) indicated that organic carbon(OC) and elemental carbo (EC) are the most emission in vehicle exhaust, over 95% of the total mass. And the diesel particulate matter and its chemical composition have important health and air pollution (Kim Oanh et al., 2010). Soret et al. (2014) concluded that vehicle electrification in Barcelona and Madrid could lead to a significant reduction of NO_2 concentration, and further reduce $PM_{2.5}$ concentration, by approximately 3–7%. Tessum et al. (2014) discussed vehicle electrification strategy in the U.S. and differences in $PM_{2.5}$ concentrations in various regions, as well as the significant improvement of air quality by reducing fuel-powered vehicles; however, electric power required for vehicle electrification caused increase in pollutants from power plants. Therefore, on the premise that natural gas, wind energy, hydro-energy or solar energy could be utilized for power generation, electric vehicle policy would reduce the adverse effects of environment on human's health by 50%.

Over the past decade (1998–2010), electric vehicles in China have been increased at an annual growth rate of 86%. Ratio of electric vehicle ownership was increased from 0 to 2 times as much as that of fuel-powered vehicles (Ji et al., 2012). In order to achieve the target of 2030 in China, Ke et al. (2017) designed the scenarios where gasoline-powered vehicles were transformed into electric vehicles. In addition, different ratios of electric vehicles were designed, and the increase in air pollutant emission due to increased consumption of coal-fired power plants for increasing power generation capacity was also taken into consideration. Ke stated that if electric vehicles in Yangtze River Delta accounted for 20% of the total number of vehicles, while gasoline-powered vehicles accounted for 80%, in winter, $PM_{2.5}$ reduction benefit would be $0.8\pm0.6\ \mu g/m^3$, and average annual $PM_{2.5}$ reduction benefit would be approximately 2–3%. If all fuel-powered vehicles were replaced with electric vehicles, taking into consideration of pollutants from power plants as a result of increased power generation capacity, reduction benefit would be $1.7\pm1.2\ \mu g/m^3$. In addition to China, India prevents deterioration of carbon emission and air quality and achieve India's Intended Nationally Determined Contribution (INDC) target, India has implemented electric vehicle policy (Dhar et al., 2017).

In the European countries, the air pollution issue of conventional vehicle has received considerable critical attention. In Ireland, electric vehicle policy has been implemented in order to reduce air pollution. Alam et al. (2018) discussed the joint reduction benefit of carbon dioxide and air pollution attributable to electric vehicle policy in Ireland in the future. This policy was mainly for promoting electric vehicles and banning conventional automobiles in 2030. For the purpose of achieving the 2020 air quality standard of the U.K. to reduce the trans-regional effects of air pollution and reduce carbon dioxide, Oxley et al. (2012) have designed various reduction scenarios, including the reduction scenario where incentives, charging infrastructure and the cost for purchasing electric vehicles were offered for transforming gasoline vehicles into electric vehicles or biofuel-powered vehicles. A certain proportion of gasoline vehicles, diesel vehicles and light duty trucks were expected to be replaced with electric vehicles by 2020. After taking into consideration of energy loss due to electric power generate and electricity fee of charging stations (assumed as 7%), it was found that electric vehicles would attribute to improving urban air quality, but it may lead to a worse result depending on the fuel used for generating additional electric power for electric vehicles.

Accordingly, Taiwan is also faced with the issue of air pollution, and the Environmental Protection Administration of Taiwan (TEPA), following the international trend as a control strategy to reduce air pollution, has also promoted electric vehicle related policy. In Dec. 2017, TEPA announced full electrification of government vehicles is expected to be implemented in 2030, full electrification of new motorcycles is expected to be implemented in 2035, and full electrification policy of automobiles is expected to be implemented in 2040. There are 21.5 million vehicles in Taiwan in 2013, the percentage of automobiles and motorcycles is 99.5% and 0.2% from electric vehicle, the other vehicle is 0.3%. If existing motorcycles are replaced with electric motorcycles, Li et al.(2016) found that power consumption would increase 5,810 million GWh; if green energy are utilized for power generation, air pollutants will be reduced by 85% as a whole, NOx concentration will be reduced by 3.3 ppb, and $PM_{2.5}$ concentration will be reduced by $2.1\ \mu g/m^3$.

Most studies in the field of air quality policies have only focused on the reduction concentration, air pollution prevention measures must be developed based on the data relating to its economic benefits or health benefits. In order to quantify the relevance between the improvement of air quality and improvement of human health, the health benefits calculation system in relation to air pollution, BenMAP (Environmental Benefits Mapping and Analysis Program), was applied for quantifying changes in health benefits before and after the improvement of air quality. Currently, this system is applied by the U.S. Environmental Protection Agency for analyzing the health benefits in relation to new air quality policy to be implemented in the future, and the health burden on people in relation to air pollution level at present or in the future.

In addition to extensive applications in analyzing state and federal air quality in the US, such as evaluation on control strategies of $PM_{2.5}$, Ozone, thermal power generation and transport pollution sources (Davidson et al., 2007; Fann et al., 2012a; Grabow et al., 2012; Ostro and Chestnut, 1998), this system has also been applied in many other countries. For example, in Spain and Korea, databases of different countries and regions are developed to be applied in conjunction with this system for evaluating health benefits(Bae and Park, 2009; Boldo et al., 2011). Moreover, Australian scholars also applied BenMAP system to evaluate the health benefits as a result of improved air quality. The results indicated that by reducing $PM_{2.5}$ concentration exposure in Sydney, Australia by 10% in 2007 for 10 years, approximately 650 premature deaths are estimated to be avoided, and 700 inpatients attributable to respiratory diseases and cardiovascular diseases are estimated to be avoided (Broome et al., 2015); a research conducted in Shanghai, China shows that as evaluated by applying BenMAP system, if PM_{10} in Shanghai meets air quality standard ($70\ \mu g/m^3$), approximately 300–800 deaths and 5,400–7,900 inpatients could be estimated to be avoided, while if PM_{10} in Shanghai meets air quality standard ($35\ \mu g/m^3$), approximately 39–1,400 deaths could be avoided (Voorhees et al., 2014).

Based on $PM_{2.5}$ concentration in 2014, Chen et al. applied BenMAP system to evaluate the health benefits for people in China when $PM_{2.5}$ concentration was reduced to $35\ \mu g/m^3$. Evaluation results show that if $PM_{2.5}$ concentration is reduced from $60.8\ \mu g/m^3$ to $35\ \mu g/m^3$, deaths attributable to cardiovascular diseases, respiratory diseases and lung cancer each year could be reduced by 89,000 people (95%CI, 8000–70,000 people), 47,000 people (95%CI, 3000–91,000 people) and 32,000 people (95%CI, 6000–58,000 people), respectively. Chen et al. applied BenMAP to discuss regional (Tianjin) reduction (Chen et al., 2016). Research results show that if average daily concentration is reduced to $75\ \mu g/m^3$, 85,000 emergency department visits could be avoided (95%CI, 17,000–150,000), 2,000 deaths attributable to cardiovascular diseases could be avoided (95%CI, 920–3100 people), and 280 deaths attributable to respiratory diseases could be avoided (95%CI, 94–460 people), respectively; related monetary values are US$

0.7–1.3 million, US$ 584.1–1557.6 million and US$ 881.2–2174.1 million, respectively. If average annual concentration is reduced to 35 μg/m^3, emergency department visits, deaths attributable to cardiovascular diseases and deaths attributable to respiratory diseases could be reduced by 59,000 people (95%CI, 12,000–110,000 people), 1,400 people (95%CI, 640–2100 people) and 200 people (95%CI, 66–320 people), respectively.

As discussed above, traffic sources have much impact for air pollution. The technique and policies of electric vehicles will be developed in these countries which have serious air pollution. To the authors' knowledge, health benefits of electric vehicles and power demands in Taiwan has been scarcely investigated.

WRF-CMAQ model was applied to assess the effect on air quality by placing additional electric power in different areas, and BenMAP system was applied to estimate the health benefits for people. Purpose of this study was mainly to discuss the effects on air quality by implementing electric vehicle policy and analysis the health benefit for additional power supply for electric vehicles should be generated to different areas. In Section II we explain the methodological and data sources. In Section III we introduce our model evaluation and detail of output data. Section IV summarizes the results and compare the cost and benefit in difference country.

2. Methodological and data

2.1. Framework

The purpose of this study is to discuss the air quality benefits generated by replacing fuel-powered motorcycles and automobiles with electric vehicles, in this study, additional power was evaluated based on the policy on promoting electric vehicles, which announced by TEPA.

Emission Inventory (TEDS9) announced by TEPA was regarded as the base emission database, and base year was set as 2013(Lai et al., 2019; Lu et al., 2019). Electric power generation scenarios: additional electric power was generated from coal-fired power plants in Northern Taiwan, Central Taiwan or Southern Taiwan, respectively. CMAQ was applied to simulate air quality, then BenMAP health benefits evaluation system developed by the US Environmental Protection Agency was applied to estimate the number of inpatients and deaths attributable to respiratory diseases and cardiovascular diseases that could be avoided. Local C-R functions were not fully developed in Taiwan, so this study use meta-analysis to health impact function of the same type of health evaluation item by using random effect approach, the process is showed as Fig. 1.

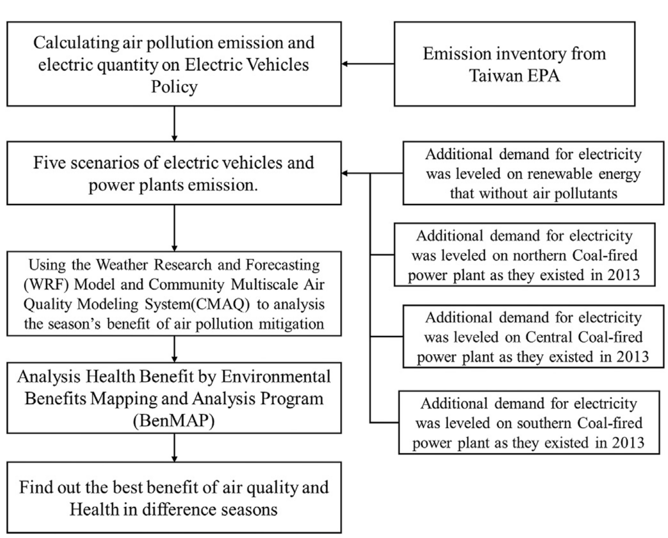

Fig. 1. Research framework.

2.2. Estimation of air pollutant emission

Emission data used in this study were derived from the TEDS9 released by TEPA and base year was set as 2013. CO, NOx and HC emissions of mobile pollution sources were estimated by applying Mobile-Taiwan2.0 model, a similar estimation method used in the US; TSP and SO_X emissions were estimated by applying the method set out in the US AP-42, Volume II: Mobile Sources -Appendix L. And power plants emission data were derived Taiwan Power Company.

In Taiwan, there are 13.73 million motorcycles, 0.01 million buses, 6.18 million light duty passenger car, 0.48 million diesel cars and 38,584 electric vehicles in 2013(MOTC, 2013). $PM_{2.5}$ emission of industry sources is 16,295 million tons/year in 2013 in total, the $PM_{2.5}$ emission of vehicles is 17,274 million tons/year, and others emission of $PM_{2.5}$ is 41,481 million tons/year. In 2013, $PM_{2.5}$ emission by coal power plants in Taiwan is 3618 tons/year in total, including 3.7% from North Taiwan, 64.8% from Central Taiwan, 35.2% from South Taiwan. NOx emission was 44,767 tons/year, including 11.1% from North Taiwan, 63.5% from Central Taiwan, 36.5% from South Taiwan. $PM_{2.5}$ emission in coal power plants account for 0.00002% in Taiwan. The $PM_{2.5}$ emission of coal power plants is less than 1% in total.

Convention vehicles is an important factor of the air quality policy. In Taiwan, NOx emission was 192,120 MT/year in total, including 7% from motorcycles, 17% from gasoline car, and 72% from diesel vehicles. $PM_{2.5}$ emission reached 17,274 MT, including 58% from diesel vehicles, 16% from motorcycles, and 3% from other types of vehicles.

From the previous discussion, it can be seen that emission of power plants is less than the emission of vehicles. Fig. 2 depicts the higher $PM_{2.5}$ emission was observed on National Highway No. 1, mainly attributable to the higher number of vehicles in Taichung City, Taoyuan City, and Kaohsiung City. As shown in Fig. 3, the largest $PM_{2.5}$ and NO_X emission source (in respect of transport) across Taiwan is diesel vehicles, followed by automobiles and motorcycles. The highest VOC emission (tons) is observed in motorcycles, followed by automobiles and diesel vehicles.

2.3. Power demand of electric vehicles policy

Estimation equation for additional power demand in relation to policy on phasing out and replacing conventional vehicles with electric vehicles proposed in the study of Li et al. (2016) was applied in this study:

$$ED = \sum_i \frac{VP_i * VU_i * VKT_i * BE_i}{TE * CE_i} \tag{1}$$

In this equation, ED refers to power demand, i refers to different types of vehicles, VP refers to the number of a specific type of vehicle, VU refers to the utilization rate of a specific type of vehicle, VKT refers to average driving mileage of a specific type of vehicle, BE refers to battery efficiency of a specific type of vehicle, TE refers to power transmission efficiency, CE refers to charger efficiency of a specific type of vehicle. Among above information, number, utilization rate and average driving mileage of vehicles were derived from TEDS9; battery efficiency data were derived from the report of the Industrial Technology Research Institute; power transmission efficiency and charger efficiency were derived from the Yearbook of

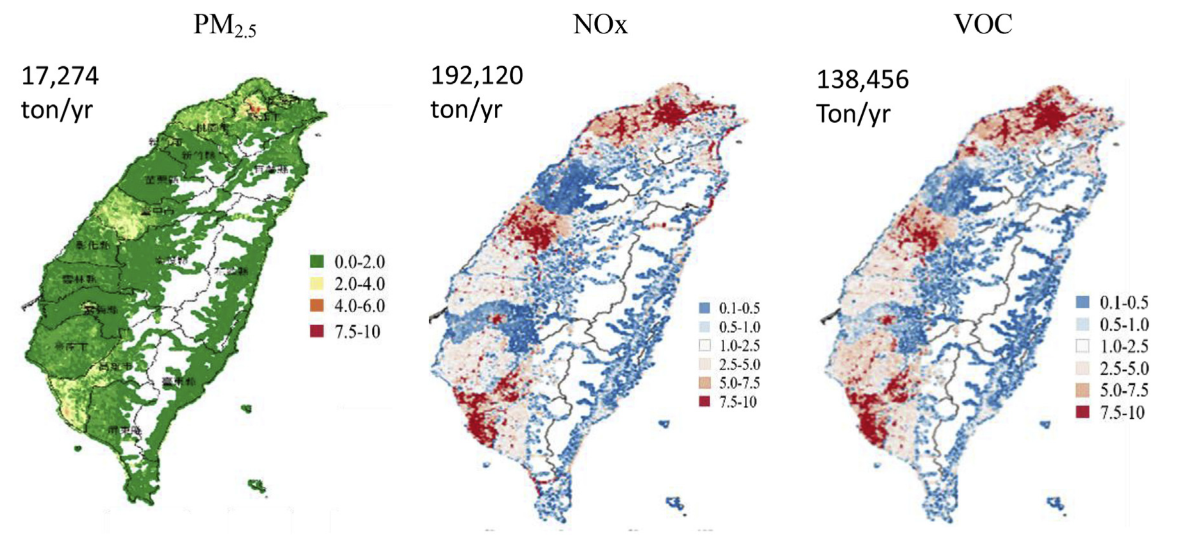

Fig. 2. Vehicles emission of $PM_{2.5}$, NO_X and VOC in 2013

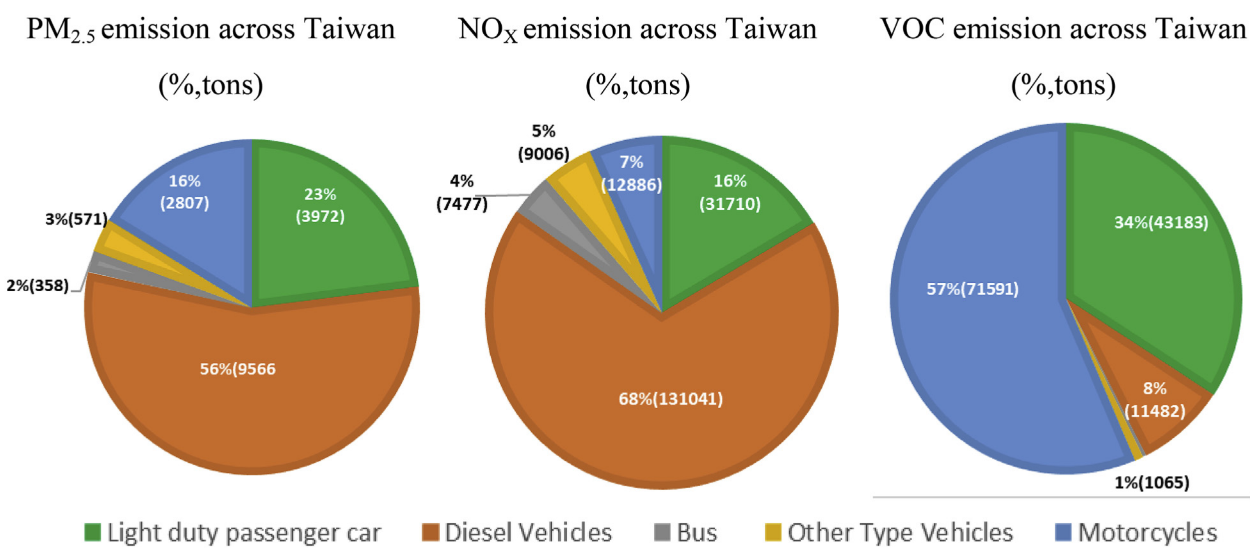

Fig. 3. Ratios of vehicles accounting for $PM_{2.5}$, NOx and VOC pollutants in 2013.

Energy-saving and New Energy Vehicle (2011 version)(CATACR, 2011). Table 1 sets out the power demand upon the implementation of electric vehicle policy in Taiwan, as estimated by applying above equation. Annual power demand of one electric bus is 4.07 kWh/year; and 18.90 kWh/year for one electric motorcycle; 313.79 kWh/year for one electric automobile; and 43.02 kWh/year for one electric diesel vehicle. Power demand is increased by 379.77 kWh/year as compared with the base power demand in 2013.

ED: power demand. i: different types of vehicles. VP: the number of a specific type of vehicle. VU: the utilization rate of a specific type of vehicle. VKT: average driving mileage of a specific type of vehicle. BE: battery efficiency of a specific type of vehicle. TE: power transmission efficiency. CE: charger efficiency of a specific type of vehicle.

Table 1
Power demand of electric vehicle.

	Bus	motorcycle	Light duty passenger car	Diesel vehicle
VP (million, number of vehicles)	0.01	13.73	6.18	0.48
VU(%)	100%	97%	100%	100%
VKT (km/year)	70.58	3.68	24.25	30.87
BE (kWh/km)	0.34	0.03	0.34	0.34
TE(%)	96%	96%	96%	96%
CE(%)	91%	91%	91%	91%
ED (kWh/year)	4.07	18.90	313.79	43.02

2.4. Air quality model

Community Multi-scale Air Quality model (CMAQ) is a model which established under the concept of “One Atmosphere Approach” for compound unified simulation engineering by integrating various pollution issues, including ozone, particulate matter (PM), acid deposition and toxic substances, for the purpose of creating the effect of interaction of simulation among different subjects and allowing model stimulation to be in line with atmospheric chemistry phenomena. With complete modules, different modules for chemical reaction mechanisms and transmission mechanisms could be replaced, for conducting scientific researches from various different perspectives. In addition, due to One-atmosphere concept, changes of various types of pollutants in different spaces could be simulated at the same time, and simulation on individual type of pollutant is not required.

CMAQ simulation system could be applied for simulating various chemical and physical processes, and such processes are of great importance in transformation and distribution of atmospheric trace gases. CMAQ simulation system consists of three types of simulation sections: (1) output of atmospheric modeling system represent the descriptions of atmospheric state; (2) emission simulation refers to results of anthropogenic and natural emissions; and (3) chemical transmission simulation module refers to the result of simulation of chemical changes. CMAQ model could be applied for simulating concentration diffusion of secondary pollutants. Furthermore, WRF meteorological model or MM5 model could be applied for simulating lateral and vertical concentration diffusion in atmosphere, to know about changes of pollutant concentrations with the passage of time. This model is commonly applied for discussing air pollution in regions and cities, such as reduction benefits to air quality as a result of implementing air quality control scheme, evaluation on effects of major pollution sources on air quality and long-range transnational transmission. In this study, the version of WRF is 3.7.1 and the version of CMAQ is 5.1, and the model output was drafted by Grid Analysis Display System (GrADs) (Doty, 1995). The model setting of WRF and CMAQ are as shown in Table 2 and Table 3.

In this study, 4-domain nested grids were applied for air quality simulation, with grid sizes of 81 km, 27 km, 9 km and 3 km. Air quality in January, April, July and October 2013 was simulated (first month of each quarter). Simulation scope is as shown in Table 4 and Fig. 4.

2.5. BenMAP

BenMAP is a set of world-leading health benefits calculation system in relation to air pollution developed by USEPA. Other countries have not developed such system yet or have directly imported such system for applications.

Table 3
Setting of CMAQ model.

Items	Description
Chemical mechanism	Cb05
Horizontal advection	Yamo
Vertical advection	WRF input
Horizontal mixing/diffusion	Multiscale
Chemistry solver	Ebi_ cb05e51_ae6_aq
aerosol	Aero 6
Cloud option	Acm ae6

Table 4
CMAQ simulation scope.

	Domain1	Domain2	Domain3	Domain4
Resolution	81 km	27 km	9 km	3 km
Grid Size	80x70	80x70	80x70	135x90

In this study, literatures of health impact function in other countries were used, including 7 papers(Beelen et al., 2014; Cesaroni et al., 2013; Crouse et al., 2012; Jerrett et al., 2013; Lepeule et al., 2012; Pope III et al., 2002; Pope et al., 2015). Then, meta-analysis was implemented to health impact function of the same type of health evaluation item by using random effect approach, respectively.

To evaluate the health benefit, mortality is often measure with changes in risk indicators in application of environmental protection. From a methodological point of view, the commonly used fatal risk monetization method is the value of statistical life (VSL)(Liou, 2019). The measurement of the value of a statistical life serves as an indicator of the estimation of the benefits of the policy, in Liu's study, uses hedonic wage model to estimate the value of a statistical life. Liu analysis age group-specific VSLs, and explores the relationship between the value of a statistical life and age from 2002 to 2006. The value of a statistical life is 3.53million USD in 2010 (Liu, 2011).

A typical health impact function specifying a log-linear relationship between risk and air quality change would look as follows (Liou, 2019; Liu, 2011):

$$y = y_0(e^{\beta\triangle x} - 1)Pop \tag{2}$$

where β is the risk coefficient drawn from an epidemiological study, Δx is the change in air quality, y0 is the baseline incidence rate for the health endpoint being quantified and Pop is the population of interest.

We estimate the sector-attributable annual mean directly

Table 2
Setting of WRF model.

Items	Description
Version	WRF v3.7.1
Meteorological data	NCEP Final Operational Global Analysis and Forecast Data (FNL)
Vertical resolution	45level
Projection coordinates	Lambert
Data assimilation	Grid Nudging and OBS nudging
Cumulus option	Kain-Fritsch
Longwave radiation option	cam scheme
Shortwave radiation option	cam scheme
Microphysics option	WSM 5-class scheme
Boundary-layer option	YSU scheme
Land surface model	4-layer soil model
Land use data	MODIS 20-category

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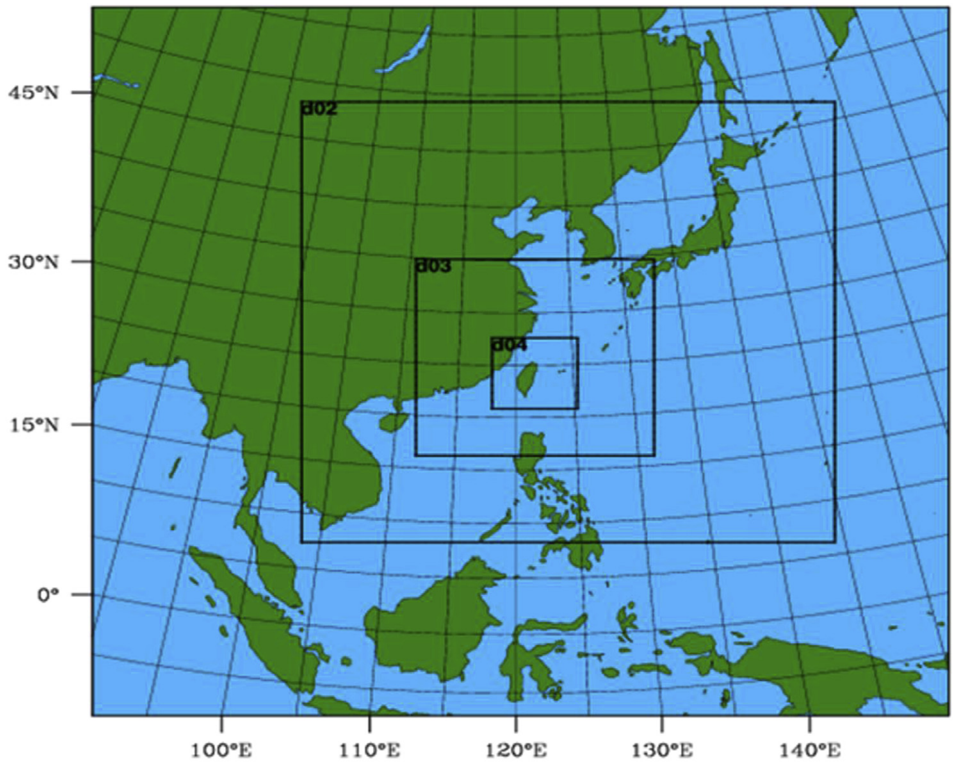

The NCAR Command Language (Version 6.6.2) [Software]. (2019). Boulder, Colorado: UCAR/NCAR/CISL/TDD. http://dx.doi.org/10.5065/D6WD3XH5

Fig. 4. Configuration of four-level nesting domains in this study.

emitted $PM_{2.5}$ across the population in each grid cell by calculating the difference between the baseline air quality scenario. BenMAP was applied to automatic this process (Fann et al., 2012a).

As discussed above, BenMAP system could be applied for evaluating the health and cost benefits as a result of air pollution control, to allow decision makers to develop sound environmental policies, and such system could be fully adapted to the analysis scale of researchers or policy makers. Analysis scope covers from cities, regions to counties and even the globe, as required. In its analysis interface, in addition to monitoring data, air pollution data could be integrated with the simulation and analysis results of various types of air quality models. Quantum GIS geographic information system (QGIS) was drafted the output(QGIS-Team, 2015). BenMAP database is set as shown in Table 5.

2.6. Scenarios assumptions

According to the Taiwan power Statistical Yearbook 2013(Taiwan-power-company, 2014), power demand of electrical vehicles in 2013 would be increased by 379 kWh(23%), as compared with the base power demand of 1642 kW in 2013, if vehicles were replaced with electric vehicles. Base scenario was the 2013 base emission derived from TEPA. From scenario 2 to scenario 4, one coal-fired power plant in Northern Taiwan, Central Taiwan and Southern Taiwan were selected for generating additional power for electric vehicles, respectively. The description of scenarios as follows:

Scenario 1(S1): all conventional vehicles were replaced with electric vehicles and air pollutants from transport are reduced to zero; power demand of electric vehicles was generated from non-thermal power plant, and it was assumed that there was no emission of any air pollutant by non-thermal energy.

Scenario 2(S2): additional power was generated from the coal-fired power plant in Northern Taiwan (Linkou Power Plant); $PM_{2.5}$, SOx and NOx emissions by the coal-fired power plant in Northern Taiwan were increased by 11.86 times, as compared with the emissions in 2013.

Scenario3(S3): additional power was generated from the coal-fired power plant in Central Taiwan (Taichung Thermal Power Plant); $PM_{2.5}$, SOx and NOx emissions by the coal-fired power plant in Central Taiwan were increased by 1.91 times, as compared with the emissions in 2013.

Table 5
BenMAP database.

Type of database	Data Description
Data of geographic domains	Domains of villages, towns, counties and cities in Taiwan and 3*3 KM grid
Pollutant monitoring data	$PM_{2.5}$ monitoring data across Taiwan in 2013
Death rate	All-cause, cardiovascular diseases and respiratory diseases in 2013
Admission rate	Cardiovascular diseases, respiratory diseases in 2013
Population data	Import of actual population in the all-age minimum statistical area in 2013
Health impact function (CR-Functions)	Meta-analysis was implemented to health impact function of the same type of health evaluation item by using random effect approach, respectively (pooling; meta-analysis). Literatures of health impact function: Paper Beelen et al., 2014; Cesaroni et al., 2013; Crouse et al., 2012; Jerrett et al., 2013; Lepeule et al., 2012; Pope III et al., 2002; Pope III et al., 2015

Scenario 4(S4): additional power was generated from the coal-fired power plant in Southern Taiwan (Hsinta Power Plant); $PM_{2.5}$, SOx and NOx emissions by the coal-fired power plant in Southern Taiwan were increased by 3.52 times as compared with the emissions in 2013. Due to different power generation capacities of different plants, air pollutant emission was increased by different times. Emission by power plants and emission by mobile sources are as summarized in Table 6.

3. Result and discussion

3.1. Model evaluation

Some previous studies (Lai et al., 2019; Lang et al., 2013) used the MM5/CMAQ or WRF/CMAQ modeling system to analysis the air pollution contribution from different pollutant emission sources, simulation results presented that meteorological/air quality models are useful tools to invest the relationship between air pollutant emission source and concentration. While modeling results should be validating before analysis, in this study, the TEPA air quality monitoring data of all regular stations (76 stations) was used to validate the $PM_{2.5}$ simulation results. According to the specifications for air quality model simulation developed by TEPA, Mean Fractional Bias (MFB) between observed value and simulated value of $PM_{2.5}$ should be ±35% and Mean Fractional Error (MFE) should be less than 55%(Chuang et al., 2018; Lai et al., 2019; TEPA, 2016). The results as shown in Table 7 indicate that annual average of air quality simulation performance in temporal and spatial are mostly qualified, even MFE in Hsinchu and Miaoli area was little more than other area, simulation data of temporal and spatial are confident to analyze the scenarios of this study.

3.2. Scenarios of additional $PM_{2.5}$ emission in different locations (and seasons)

The aim to examine the additional air pollutant emission is to fit the optimal solution of electric vehicles policy, that is to making less air pollutants concentration when required emission is increasing. To demonstrate the comparison baseline, the spatial distribution of air pollution could learn from the annual monitoring report of Taiwan (TEPA, 2013), it illustrated that the highest $PM_{2.5}$ concentration was in southern Taiwan with an average $PM_{2.5}$ concentration of 38.11 μg/m^3, followed by Yunlin-Chiayi-Tainan area a little norther to the most serious area, with an average $PM_{2.5}$ concentration of 34.68 μg/m^3. Moreover, as in view of season, it showed that the worst season of air quality happened in winter. Fang and Chang (2010) demonstrated the winter synoptic northeastern wind would transport the $PM_{2.5}$ from north to south, which accumulated the air pollutants in southern Taiwan. Therefore, in this study, we examine the optimal locations to offer the additional electricity with more emission in existed power plants to reach the benefit of air quality from electric vehicles policy.

First of all, the effect of reducing transportation air pollutants was assessed. In the simulation experiment, mobile source emission was dropped to zero for presenting the replacement of electric vehicles from conventional ones (scenario S1). As shown in Fig. 5, the reduction of annual average concentration of $PM_{2.5}$ in northern Taiwan, Hsinchu and Miaoli area, Central Taiwan, Yunlin-Chiayi-Tainan area and Kaohsiung-Pingtung area are 2.31 μg/m^3, 2.06 μg/m^3, 3.75 μg/m^3, 3.31 μg/m^3, and 5.28 μg/m^3, respectively. In average, electric vehicles policy can reduced 23% emission reduction and 14.5% concentration from transportation sector in Taiwan, it is quite similar with the other countries, Ireland got 11.7% reduction on $PM_{2.5}$ concentration (Alam et al., 2018) and 24.7% in China (Wang et al., 2015) when adopt the electric vehicles policy. These results showed the transportation control policy could reduce the air pollution around 10–25%.

In particular, there is spatial characteristic we found in Taiwan. From S1, it showed the electric vehicles policy will reduce 29% transportation $PM_{2.5}$ emissions in northern Taiwan and earn 2.31 μg/m^3 concentration decreasing; when compared with southern Taiwan, even less transportation $PM_{2.5}$ emission was reduced (19%)

Table 6
Descriptions of scenarios.

Emission (tons/year)	$PM_{2.5}$		NOx		SOx		VOC	
	Power plant Emission ratio	Taiwan Transportation	Power plant Emission ratio	Taiwan Transportation	Power plant Emission ratio	Taiwan Transportation	Power plant Emission ratio	Taiwan Transportation
Base	Northern Taiwan 77.3	17274	Northern Taiwan 4488.3	192120	Northern Taiwan 1301.5	139	Northern Taiwan 1.3	20594
	Central 1361.2		Central 25559.8		Central 16409.1		Central 2.9	
	Southern Taiwan 739.3		Southern Taiwan 14719.3		Southern Taiwan 11945.4		Southern Taiwan 1.4	
S1	Northern Taiwan 77.3	0	Northern Taiwan 4488.3	0	Northern Taiwan 1301.5	0	Northern Taiwan 1.3	0
	Central 1361.2		Central 25559.8		Central 16409.1		Central 3.0	
	Southern Taiwan 739.3		Southern Taiwan 14719.3		Southern Taiwan 11945.4		Southern Taiwan 1.4	
S2	Northern Taiwan 917.0	0	Northern Taiwan 53231.8	0	Northern Taiwan 15435.7	0	Northern Taiwan 15.6	0
	Central 1361.2		Central 25559.8		Central 16409.1		Central 2.9	
	Southern Taiwan 739.3		Southern Taiwan 14719.3		Southern Taiwan 11945.4		Southern Taiwan 1.4	
S3	Northern Taiwan 77.3	0	Northern Taiwan 4488.3	0	Northern Taiwan 1301.5	0	Northern Taiwan 1.3	0
	Central 4012.8		Central 48819.1		Central 31341.4		Central 5.6	
	Southern Taiwan 739.3		Southern Taiwan 14719.3		Southern Taiwan 11945.4		Southern Taiwan 1.4	
S4	Northern Taiwan 77.3	0	Northern Taiwan 4488.3	0	Northern Taiwan 1301.5	0	Northern Taiwan 1.3	0
	Central 1361.2		Central 25559.8		Central 16409.1		Central 2.9	
	Southern Taiwan 2602.3		Southern Taiwan 51812.1		Southern Taiwan 42047.8		Southern Taiwan 4.8	

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Table 7
CMAQ model performance validation.

$PM_{2.5}$ Performance	January		April		July		October		Average annual	
	MFB	MFE	MFB	MFE	MFB	MFE	MFB	MFE	MFB	MFE
Northern air quality area	−22%	24%	−24%	30%	−17%	19%	−39%	39%	26%	28%
Hsinchu and Miaoli air quality area	−29%	32%	−34%	40%	−36%	36%	−51%	51%	−38%	40%
Central air quality area	−19%	24%	−33%	37%	−41%	43%	−25%	28%	−30%	33%
Yunlin-Chiayi-Tainan air quality area	−33%	34%	−39%	41%	−34%	37%	−31%	32%	−34%	36%
Kaohsiung-Pingtung air quality area	−21%	23%	−25%	27%	−30%	31%	−16%	17%	−23%	25%

MFB: mean fractional bias (%), MFE: mean fractional error (%).

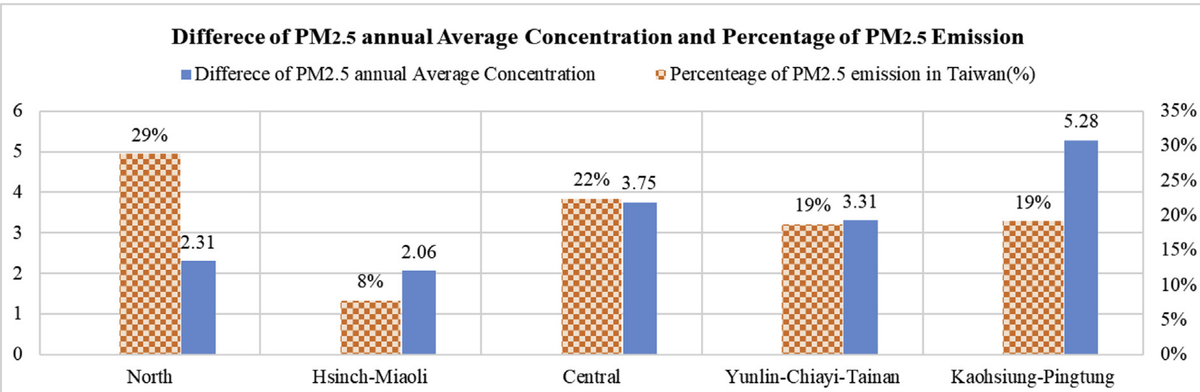

Fig. 5. Difference of $PM_{2.5}$ annual concentration and Percentage of $PM_{2.5}$ emission of transportation in Taiwan.

but more concentration (5.28 μg/m^3) is earned. It is interesting and also important to study the air quality benefit on different locations of additional electricity power generation. However, the increasing emission will be limited on the location of present power plants, the simulation experiments set the three scenarios based on the locations of present power plants in section 2.

From the results of scenarios simulation, spatial distribution of annual average concentration reduction was showed in Fig. 6, it presented the additional electric power for electric vehicles which generated from the coal-fired power plant in southern area seemed got the better benefits than northern and central Taiwan. However, from the previously discussion, additional pollutants emitted from the coal-fired power plant in northern Taiwan would be transmitted to the downwind area, thus pollutants would be prone to accumulate at central and southern Taiwan, and made worse air quality instead of northern Taiwan. The effect of wind transportation also could find in S4, the concentration distribution depicted that if the additional power for electric vehicles generated from the coal-fired power plant in southern Taiwan, the air pollutants will accumulate in southern area only.

In addition, a special characteristic was found according to the simulation results in these scenarios. When compared with each scenario in summer, S2 has better air quality benefit; by contrast, the benefit of air quality was better in S4 in winter (Fig. 7). The characteristics was also found in other areas where the seasonal winds dominate the accumulation of air pollutants, such as in China, 8−13% of $PM_{2.5}$ concentration in Beijing-Tianjin-Hebei area was contributed by power plants emission, and only 0.3−0.4% was accumulated in the southern Heibei due to strong seasonal winds(Wang et al., 2013).

To summary the scenarios analysis, there are two findings could present by Fig. 7 which showed the air quality effect of power demand generated in different areas in four seasons. The first finding is the additional power demand by electric vehicles policy will increase air pollution but the quantity is small. The annual average trend in each individual situation were very similar, the difference of concentration reduction among all scenarios was small only differ from 0.1 to 0.7 μg/m^3(0.4%−3.2%). It is consistent with the similar economic and geographic country like Korea, Kim et al.(2016) showed the 2.4% (0.63 μg/m^3) of annual $PM_{2.5}$ concentration was contributed by fossil-fuel power plants in South Korea.

The second finding is from the spatial and seasonal analysis, according to Fig. 7, the optimal air quality benefits in respect of additional power generation for electric vehicles could adjust in different seasons. It is recommended to generate additional power from the power plant in northern Taiwan in summer (2.50 μg/m^3 reduced) and from the power plant in southern Taiwan in winter (4.39 μg/m^3 reduced). These results also demonstrated when not considering the power grid transmission loss or supply, the location of additional power generation should be involved in air quality policy design.

3.3. Health benefits in relation to $PM_{2.5}$ concentration reduction in different scenarios

After examined the air quality benefits on different scenarios of $PM_{2.5}$ reductions, this study uses BenMAP to evaluate the quantitative health benefits in different scenarios of improving $PM_{2.5}$ levels accordingly. BenMAP was applied to estimate the number of deaths and inpatients attributable to cardiovascular and respiratory diseases avoided in different scenarios(Broome et al., 2015; Fann et al., 2012a; Fann et al., 2016; Fann et al., 2012b; Sacks et al., 2018).

Based on the data in 2013, all relevant factors, including population, admission rate and price index, were derived from data in 2013. As estimated by applying BenMAP, the health benefits in the scenario where replacing conventional vehicles across Taiwan with electric vehicles were: 11,545 deaths and 44.15 billion USD attributable to cardiovascular and respiratory diseases could be avoided, and 3,926 and 2,421 inpatients attributable to respiratory and

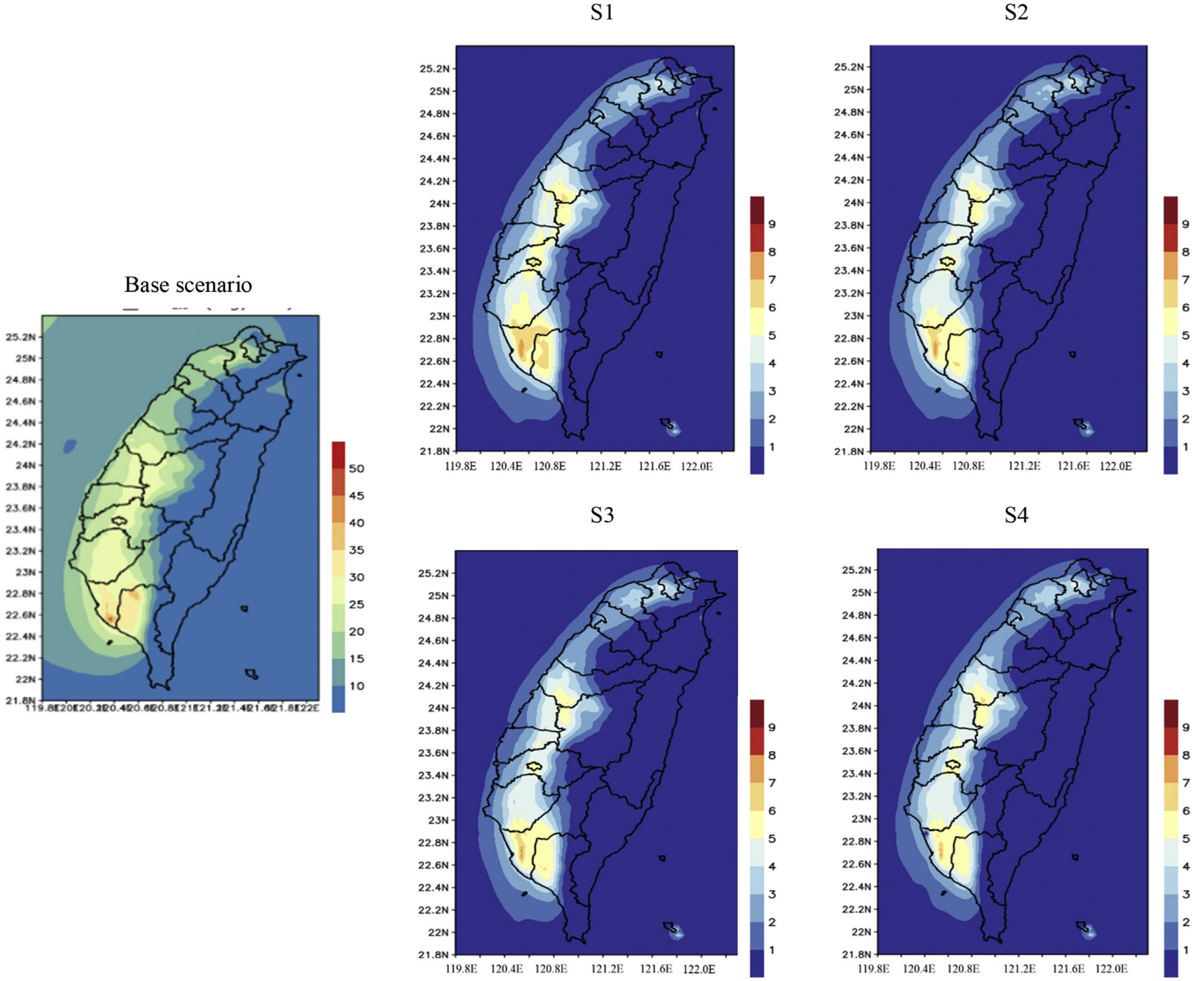

Fig. 6. $PM_{2.5}$ annual concentration differences in different scenarios($\mu g/m^3$).
(S1: Scenario1 Replacing conventional vehicles with electric vehicles, S2: Generate additional power from coal-fired power plants in Northern Taiwan on an average basis, S3: generate additional power from the coal-fired power plant in Central Taiwan, S4: Reducing additional power to the coal-fired power plant in Southern Taiwan).

cardiovascular diseases could be avoided, respectively. The health benefit are quite different in different countries due to the difference in population and GDP, for example in China, Guo et al. (2010) who demonstrated the total economic cost of health impacts due to air pollution contributed from transportation sector in Beijing in 2008 was 298 million USD, these studies implied the air quality/health benefit needs to self-alignment continuously.

The health benefits from different scenarios were showed in Table 8, in the scenario S2 there were 11,336 deaths and 43.35 billion USD could be avoided; 3,853 and 2,376 inpatients attributable to respiratory and cardiovascular diseases could be avoided. In scenario S3, 11,347 deaths and 43.4 billion USD could be avoided; 3,856 and 2,380 inpatients attributable to respiratory and cardiovascular diseases could be avoided. The same analysis in S4 presented 11,387 deaths and 43.54 billion USD could be avoided; 3,870 and 2,387 inpatients attributable to respiratory and cardiovascular diseases could be avoided, respectively. In average, the difference between scenarios is not patency, but for the health consideration, it need to examine more detail.

In view of the above results, the best health benefits were observed in the scenario where additional power were generated by non-thermal energy(S1), followed by the scenario where additional power were generated from the power plant in southern Taiwan (S4) and the scenario where additional power were generated from the power plant in central Taiwan (S3). Table 8 and Fig. 8 also shows that in respect of health benefits, deaths avoided in the scenario where additional power are generated by non-thermal energy (S1) are 209 people more than those in the scenario where additional power for electric vehicles are generated from the power plant in northern Taiwan (S1), this is mainly because that northern Taiwan is the most densely populated area in Taiwan, and health benefits for people will be significantly affected in case of just a slight concentration difference.

This also accords with the earlier observations, which showed that additional power was generated from power plants in different areas, the areas on the leeward area of power plant would be affected. From the perspective of health benefits for people, if additional power for electric vehicles cannot be generated by non-

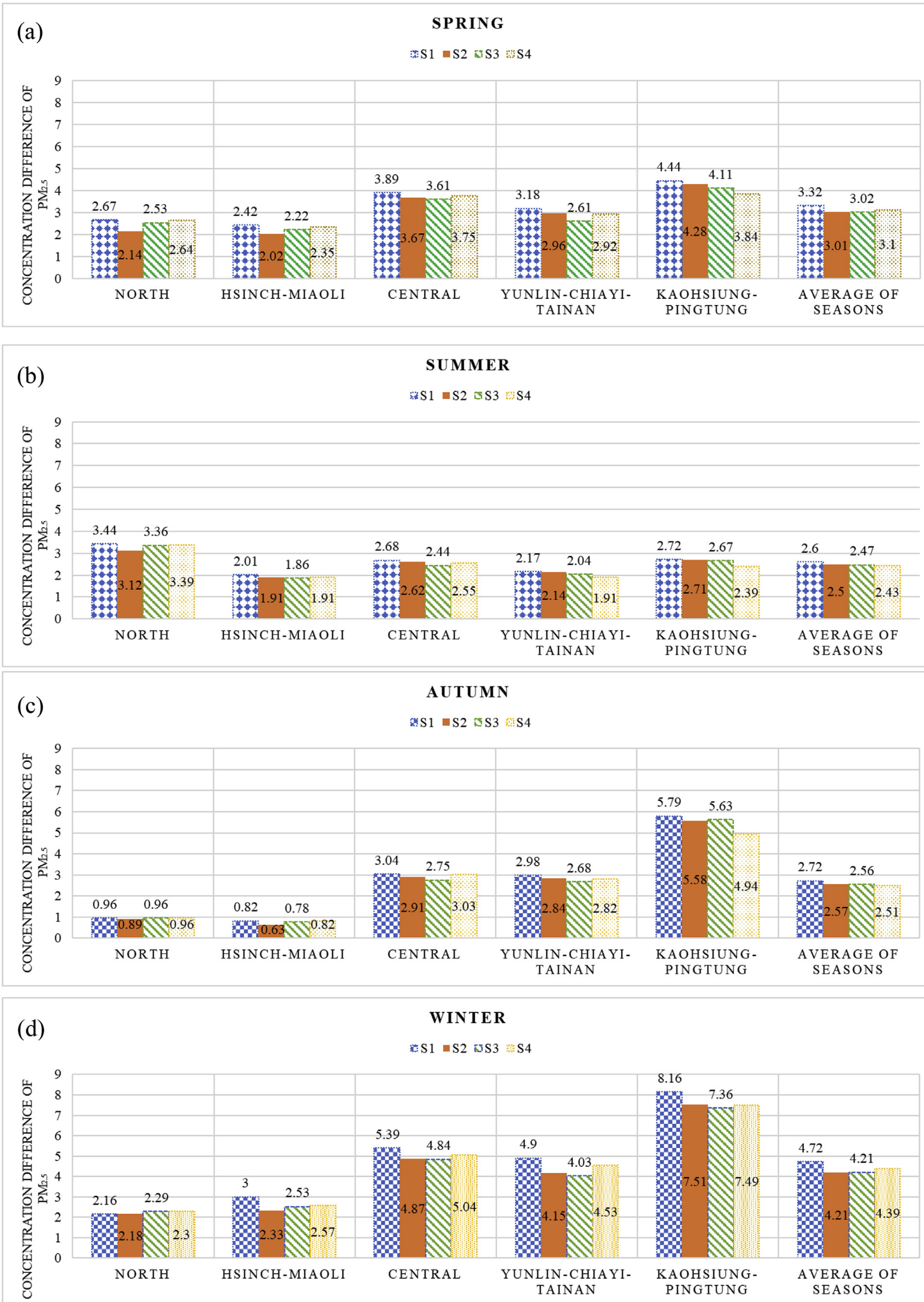

Fig. 7. Difference areas of $PM_{2.5}$ concentration reduction in four seasons: (a) spring, (b) summer, (c) autumn, (d) winter ($\mu g/m^3$)(
S1: Scenario1 Replacing conventional vehicles with electric vehicles, S2: Generate additional power from coal-fired power plants in Northern Taiwan on an average basis, S3:Generate additional power from the coal-fired power plant in Central Taiwan, S4: Reducing additional power to the coal-fired power plant in Southern Taiwan).

Table 8
Heath benefits for people in different scenarios.

Health Endpoint	$PM_{2.5}$-related mortality		$PM_{2.5}$-related cardiovascular hospitalizations		$PM_{2.5}$-related respiratory hospitalizations	
	Health Events Avoided (95% CI)	Mean Valuation (billion USD) (95% CI)	Health Events Avoided (95% CI)	Mean Valuation (million USD) (95% CI)	Health Events Avoided (95% CI)	Mean Valuation (million USD) (95% CI)
S1	11,545 (4,336–25,715)	44.15 (16.58–98.34)	2,421 (720–4,101)	7.77 (2.31–13.17)	3,926 (0–10,330)	10.79 (0–28.41)
S2	11,336 (4,256–25,286)	43.35 (16.28–96.69)	2,376 (706–4,024)	7.63 (2.27–12.92)	3,853 (0–10,396)	10.86 (0–28.59)
S3	11,347 (4,260–25,318)	43.40 (16.29–96.82)	2,380 (707–4,031)	7.64 (2.27–12.94)	3,856 (0–10,150)	10.60 (0–27.91)
S4	11,387 (4,275–25,402)	43.54 (16.34–97.14)	2,387 (710–4,044)	7.67 (2.28–12.98)	3,870 (0–10,185)	10.64 (0–28.01)

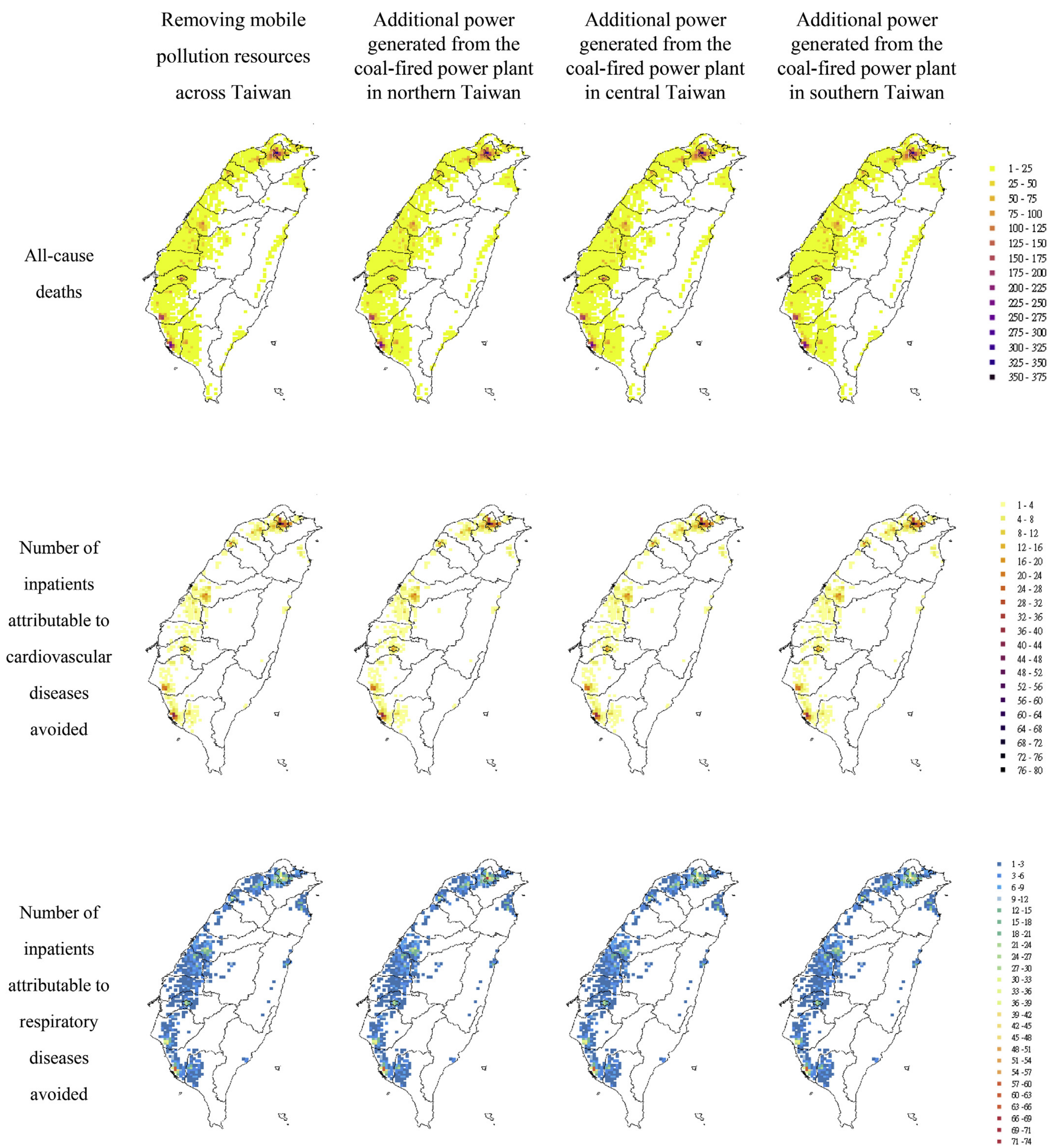

Fig. 8. Number of people affected in different scenarios.

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thermal energy, it is recommended to generate the additional power from the power plant in southern Taiwan, and this move will greatly contribute to the health benefits for people in Taiwan.

4. Conclusion

This study was conducted to estimate the effect of electric vehicles, also the additional power demand was considered in air quality policy, both of CMAQ and BenMAP were applied to evaluate air quality and health benefits to make the integrated policy support information.

The evaluation presents replacement by the electric vehicles will improve the air quality of Taiwan dramatically, the results imply that transportation emission reduction is very critical in air quality attainment. Second, the analysis of seasonal scenarios also indicates the location to generate additional electricity power is important when adapting electric vehicle policy. Even the emission reduction in electric vehicle policies in northern Taiwan was the largest(4826tons/year, 29%), both of the concentration reduction(2.31 $\mu g/m^3$) was the least, but in another side, the reduction emission of transportation arranged in order in descending were northern (4826tons/year, 29%), southern (3204tons/year, 19.1%) and central Taiwan (3746tons/year, 22.4%), however, when the additional power generated in southern, central and northern Taiwan, the $PM_{2.5}$ reduction concentration and public health will be better in descending order.

Findings of this study were improved the policy of electric vehicles is useful to the air quality and the health benefit. Further research could usefully explore how to calculate the power consumption of transportation, the economic benefits which required for the infrastructure construction. The battery charging station and terminal power consumption may increase, and the loss of related infrastructure needs to be considered.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2019.119152.

References

Alam, M.S., Hyde, B., Duffy, P., McNabola, A., 2018. Analysing the Co-Benefits of transport fleet and fuel policies in reducing PM2.5 and CO2 emissions. J. Clean. Prod. 172, 623–634.
Bae, H.J., Park, J., 2009. Health benefits of improving air quality in the rapidly aging Korean society. Sci. Total Environ. 407 (23), 5971–5977.
Beelen, R., Raaschou-Nielsen, O., Stafoggia, M., Andersen, Z.J., Weinmayr, G., Hoffmann, B., Wolf, K., Samoli, E., Fischer, P., Nieuwenhuijsen, M., 2014. Effects of long-term exposure to air pollution on natural-cause mortality: an analysis of 22 European cohorts within the multicentre ESCAPE project. The Lancet 383 (9919), 785–795.
Boldo, E., Linares, C., Lumbreras, J., Borge, R., Narros, A., Garcia-Perez, J., Fernandez-Navarro, P., Perez-Gomez, B., Aragones, N., Ramis, R., Pollan, M., Moreno, T., Karanasiou, A., Lopez-Abente, G., 2011. Health impact assessment of a reduction in ambient PM(2.5) levels in Spain. Environ. Int. 37 (2), 342–348.
Broome, R.A., Fann, N., Cristina, T.J., Fulcher, C., Duc, H., Morgan, G.G., 2015. The health benefits of reducing air pollution in Sydney, Australia. Environ. Res. 143 (Pt A), 19–25.
CATACR, 2011. Energy Saving and New Energy Vehicle Yearbook. Guoneng Yingchuang Energy and Information Technology Ltd., Energy Saving and New Energy Vehicle Yearbook Edit Office, Beijing, P. R. China.
Cesaroni, G., Badaloni, C., Gariazzo, C., Stafoggia, M., Sozzi, R., Davoli, M., Forastiere, F., 2013. Long-term exposure to urban air pollution and mortality in a cohort of more than a million adults in Rome. Environ. Health Perspect. 121 (3), 324–331.
Chen, L., Shi, M., Gao, S., Suhuan, L., Mao, J., Zhang, H., Sun, Y., Bai, Z., Zhongliang, W., 2016. Assessment of population exposure to $PM_{2.5}$ for mortality in China and its public health benefit based on BenMAP. Environ. Pollut. 221, 311–317. https://doi.org/10.1016/j.envpol.2016.11.080.
Chuang, M.-T., Lee, C.-T., Hsu, H.-C., 2018. Quantifying PM2.5 from long-range transport and local pollution in Taiwan during winter monsoon: an efficient estimation method. J. Environ. Manag. 227, 10–22.
Crouse, D.L., Peters, P.A., van Donkelaar, A., Goldberg, M.S., Villeneuve, P.J., Brion, O., Khan, S., Atari, D.O., Jerrett, M., Pope III, C.A., 2012. Risk of nonaccidental and cardiovascular mortality in relation to long-term exposure to low concentrations of fine particulate matter: a Canadian national-level cohort study. Environ. Health Perspect. 120 (5), 708–714.
Davidson, K., Hallberg, A., McCubbin, D., Hubbell, B., 2007. Analysis of PM2.5 using the environmental benefits mapping and analysis Program (BenMAP). J. Toxicol. Environ. Health Part A 70 (3–4), 332–346.
Dhar, S., Pathak, M., Shukla, P.R., 2017. Electric vehicles and India's low carbon passenger transport: a long-term co-benefits assessment. J. Clean. Prod. 146, 139–148.
Doty, B., 1995. The grid analysis and display system. GRADS Manual 10, 148.
Fang, G.-C., Chang, S.-C., 2010. Atmospheric particulate (PM10 and PM2.5) mass concentration and seasonal variation study in the Taiwan area during 2000–2008. Atmos. Res. 98 (2), 368–377.
Fann, N., Baker, K.R., Fulcher, C.M., 2012a. Characterizing the $PM_{2.5}$-related health benefits of emission reductions for 17 industrial, area and mobile emission sectors across the U.S. Environ. Int. 49, 141–151.
Fann, N., Gilmore, E.A., Walker, K., 2016. Characterizing the long-term $PM_{2.5}$ concentration-response function: comparing the strengths and weaknesses of research synthesis approaches. Risk Anal. 36 (9), 1693–1707.
Fann, N., Lamson, A.D., Anenberg, S.C., Wesson, K., Risley, D., Hubbell, B.J., 2012b. Estimating the national public health burden associated with exposure to ambient $PM_{2.5}$ and ozone. Risk Anal.: Int. J. 32 (1), 81–95.
Grabow, M.L., Spak, S.N., Holloway, T., Stone, B., Mednick, A.C., Patz, J.A., 2012. Air quality and exercise-related health benefits from reduced car travel in the midwestern United States. Environ. Health Perspect. 120 (1), 68–76.
Guo, X., Cheng, S., Chen, D., Zhou, Y., Wang, H., 2010. Estimation of economic costs of particulate air pollution from road transport in China. Atmos. Environ. 44 (28), 3369–3377.
IARC, 2013. Outdoor Air Pollution a Leading Environmental Cause of Cancer Deaths. nternational Agency for Research on Cancer.
Jerrett, M., Burnett, R.T., Beckerman, B.S., Turner, M.C., Krewski, D., Thurston, G., Martin, R.V., van Donkelaar, A., Hughes, E., Shi, Y., 2013. Spatial analysis of air pollution and mortality in California. Am. J. Respir. Crit. Care Med. 188 (5), 593–599.
Ji, S., Cherry, C.R., J Bechle, M., Wu, Y., Marshall, J.D., 2012. Electric vehicles in China: emissions and health impacts. Environ. Sci. Technol. 46 (4), 2018–2024.
Ke, W., Zhang, S., Wu, Y., Zhao, B., Wang, S., Hao, J., 2017. Assessing the future vehicle fleet electrification: the impacts on regional and urban air quality. Environ. Sci. Technol. 51 (2), 1007–1016.
Kim Oanh, N.T., Thiansathit, W., Bond, T.C., Subramanian, R., Winijkul, E., Pawarmart, I., 2010. Compositional characterization of PM2.5 emitted from in-use diesel vehicles. Atmos. Environ. 44 (1), 15–22.
Lai, H.-C., Ma, H.-W., Chen, C.-R., Hsiao, M.-C., Pan, B.-H., 2019. Design and application of a hybrid assessment of air quality models for the source apportionment of PM2.5. Atmos. Environ. 212, 116–127.
Lang, J.-L., Cheng, S.-Y., Li, J.-B., Chen, D.-S., Zhou, Y., Wei, X., Han, L.-H., Wang, H.-Y., 2013. A monitoring and modeling study to investigate regional transport and characteristics of PM2. 5 pollution. Aerosol and Air Quality Res. 13 (3), 943–956.
Lepeule, J., Laden, F., Dockery, D., Schwartz, J., 2012. Chronic exposure to fine particles and mortality: an extended follow-up of the Harvard Six Cities study from 1974 to 2009. Environ. Health Perspect. 120 (7), 965–970.
Li, N., Chen, J.-P., Tsai, I.C., He, Q., Chi, S.-Y., Lin, Y.-C., Fu, T.-M., 2016. Potential impacts of electric vehicles on air quality in Taiwan. Sci. Total Environ. 566–567, 919–928.
Liou, J.-L., 2019. Effect of income heterogeneity on valuation of mortality risk in Taiwan: an application of unconditional quantile regression method. Int. J. Environ. Res. Public Health 16 (9), 1620.
Liu, J.-L., 2011. The Older the Less Vaue?— an Analysis in the Effect of Age on the Value of Life. National Central University.
Lu, H.-Y., Wu, Y.-L., Mutuku, J.K., Chang, K.-H., 2019. Various sources of PM2. 5 and their impact on the air quality in Tainan city, Taiwan. Aerosol and Air Quality Res. 19, 601–619.
MOTC, 2013. Vehicles Statistics of Ministry of Transportation and Communications.
Ostro, B., Chestnut, L., 1998. Assessing the health benefits of reducing particulate matter air pollution in the United States. Environ. Res. 76 (2), 94–106.
Oxley, T., Elshkaki, A., Kwiatkowski, L., Castillo, A., Scarbrough, T., ApSimon, H., 2012.

Pollution abatement from road transport: cross-sectoral implications, climate co-benefits and behavioural change. Environ. Sci. Policy 19–20, 16–32.
Pope III, C.A., Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K., Thurston, G.D., 2002. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. Jama 287 (9), 1132–1141.
Pope III, C.A., Turner, M.C., Burnett, R.T., Jerrett, M., Gapstur, S.M., Diver, W.R., Krewski, D., Brook, R.D., 2015. Relationships between fine particulate air pollution, cardiometabolic disorders, and cardiovascular mortality. Circ. Res. 116 (1), 108–115.
QGIS-Team, 2015. QGIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgis.osgeo.org.
Sacks, J.D., Lloyd, J.M., Zhu, Y., Anderton, J., Jang, C.J., Hubbell, B., Fann, N., 2018. The Environmental Benefits Mapping and Analysis Program–Community Edition (BenMAP–CE): a tool to estimate the health and economic benefits of reducing air pollution. Environ. Model. Softw 104, 118–129.
Soret, A., Guevara, M., Baldasano, J.M., 2014. The potential impacts of electric vehicles on air quality in the urban areas of Barcelona and Madrid (Spain). Atmos. Environ. 99, 51–63.
Taiwan-power-company, 2014. Taiwan Power Statistical Yearbook 2013.
TEPA, 2013. Air Quality Annual Report of R.O.C.(Taiwan),2013.
TEPA, 2016. New Air Quality Modeling and Simulation Standards.
Tessum, C.W., Hill, J.D., Marshall, J.D., 2014. Life Cycle Air Quality Impacts of Conventional and Alternative Light-Duty Transportation in the United States, vol. 111, pp. 18490–18495, 52.
Voorhees, A.S., Wang, J., Wang, C., Zhao, B., Wang, S., Kan, H., 2014. Public health benefits of reducing air pollution in Shanghai: a proof-of-concept methodology with application to BenMAP. Sci. Total Environ. 485–486, 396–405.
Wang, L., Liu, Z., Sun, Y., Ji, D., Wang, Y., 2015. Long-range transport and regional sources of PM2.5 in Beijing based on long-term observations from 2005 to 2010. Atmos. Res. 157, 37–48.
Wang, L., Wei, Z., Yang, J., Zhang, Y., Zhang, F., Su, J., Meng, C., Zhang, Q., 2013. The 2013 severe haze over the southern Hebei, China: model evaluation, source apportionment, and policy implications. Atmos. Chem. Phys. Discuss. 13 (11).
Watson, J.G., Chow, J.C., Houck, J.E., 2001. PM2.5 chemical source profiles for vehicle exhaust, vegetative burning, geological material, and coal burning in Northwestern Colorado during 1995. Chemosphere 43 (8), 1141–1151.
WHO, 2015. Economic Cost of the Health Impact of Air Pollution in Europe: Clean Air, Health and Wealth. WHO Regional Office for Europe.

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