Trinity College Dublin
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INTEGRATED TRANSPORTATION AND LAND USE REGRESSION MODELLING FOR NO_2 MITIGATION

VOLUME 2

Aonghus Ó Domhnaill

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Dissertation submitted in fulfilment of the requirements for the Degree of Doctor of Philosophy (PhD) in Civil, Structural and Environmental Engineering.

Submission Date: 30th April 2022

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Appendix A

Appendix A: Vehicle Breakdown Analysis Variable Percentage Annotations

Table A1: Light Commercial Vehicles (LCVs) Vehicle Breakdown and Annotations

VEHICLE TYPE (*v*)	VEHICLE TYPE % (V_v)	FUEL TYPE (*f*)	FUEL TYPE % ($F_{v,f}$)	VEHICLE SUB-TYPE (ENGINE CAPACITY CATEGORY OR UNLADEN WEIGHT CATEGORY) (*s*)	VEHICLE SUB-TYPE % (v_s)	ENGINE CAPACITY % ($E_{v,s}$)	UNLADEN WEIGHT % ($U_{v,s}$)	WEIGHTING FACTOR % (W_v)	GROUP NUMBER (*n*)	EURO CLASSIFICATION (*e*)	VEHICLE SUB-TYPE BREAKDOWN BY EURO CLASS % ($T_{v,s,n,e}$)	EURO CLASS % ($v_{s,e}$)
Light Commercial Vehicles (LCV)	V_{LCV}	Petrol (P)	$F_{LCV,P}$	Petrol (P)	LCV_P	-	$U_{LCV,P}$	-	1	Conventional	$T_{LCV,P,1,CN}$	$LCV_{P,CN}$
										Euro 1 - 93/59/EEC	$T_{LCV,P,1,E1}$	$LCV_{P,E1}$
										Euro 2 - 96/69/EEC	$T_{LCV,P,1,E2}$	$LCV_{P,E2}$
										Euro 3 - 98/69/EC I	$T_{LCV,P,1,E3}$	$LCV_{P,E3}$
										Euro 4 - 98/69/EC II	$T_{LCV,P,1,E4}$	$LCV_{P,E4}$
										Euro 5 - EC 715/2007	$T_{LCV,P,1,E5}$	$LCV_{P,E5}$
										Euro 6 up to 2017	$T_{LCV,P,1,E6-2017}$	$LCV_{P,E6-2017}$
										Euro 6 2018 - 2020	$T_{LCV,P,1,E6-2020}$	$LCV_{P,E6-2020}$
		Diesel (D)	$F_{LCV,D}$	Diesel (D)	LCV_D	-	$U_{LCV,D}$	-	1	Conventional	$T_{LCV,D,1,CN}$	$LCV_{D,CN}$
										Euro 1 - 93/59/EEC	$T_{LCV,D,1,E1}$	$LCV_{D,E1}$

VEHICLE TYPE (*v*)	VEHICLE TYPE % (V_v)	FUEL TYPE (*f*)	FUEL TYPE % ($F_{v,f}$)	VEHICLE SUB-TYPE (ENGINE CAPACITY CATEGORY OR UNLADEN WEIGHT CATEGORY) (*s*)	VEHICLE SUB-TYPE % (v_s)	ENGINE CAPACITY % ($E_{v,s}$)	UNLADEN WEIGHT % ($U_{v,s}$)	WEIGHTING FACTOR % (W_v)	GROUP NUMBER (*n*)	EURO CLASSIFICATION (*e*)	VEHICLE SUB-TYPE BREAKDOWN BY EURO CLASS % ($T_{v,s,n,e}$)	EURO CLASS % ($v_{s,e}$)
										Euro 2 - 96/69/EEC	$T_{LCV,D,1,E2}$	$LCV_{D,E2}$
										Euro 3 - 98/69/EC I	$T_{LCV,D,1,E3}$	$LCV_{D,E3}$
										Euro 4 - 98/69/EC II	$T_{LCV,D,1,E4}$	$LCV_{D,E4}$
										Euro 5 - EC 715/2007	$T_{LCV,D,1,E5}$	$LCV_{D,E5}$
										Euro 6 up to 2017	$T_{LCV,D,1,E6-2017}$	$LCV_{D,E6-2017}$
										Euro 6 2018 - 2020	$T_{LCV,D,1,E6-2020}$	$LCV_{D,E6-2020}$

Table A2: Heavy Duty Vehicles (HDVs) Vehicle Breakdown and Annotations

VEHICLE TYPE (*v*)	VEHICLE TYPE % (V_v)	FUEL TYPE (*f*)	FUEL TYPE % ($F_{v,f}$)	VEHICLE SUB-TYPE (ENGINE CAPACITY CATEGORY OR UNLADEN WEIGHT CATEGORY) (*s*)	VEHICLE SUB-TYPE % (v_s)	ENGINE CAPACITY % ($E_{v,s}$)	UNLADEN WEIGHT % ($U_{v,s}$)	WEIGHTING FACTOR % (W_v)	GROUP NUMBER (*n*)	EURO CLASSIFICATION (*e*)	VEHICLE SUB-TYPE BREAKDOWN BY EURO CLASS % ($T_{v,s,n,e}$)	EURO CLASS % ($v_{s,e}$)
Heavy-Duty Vehicles (HDV)	V_{HDV}	Petrol (P)	$F_{HDV,P}$	Petrol >3.5t	HDV_P	-	$U_{HDV,P}$	-	2	Conventional	$T_{HDV,P,2,CN}$	$HDV_{P,CN}$
		Diesel (D)	$F_{HDV,D}$	Diesel ≤7.5t	$HDV_{D7.5}$	-	$U_{HDV,D7.5}$	-	1	Conventional	$T_{HDV,D7.5,1,CN}$	$HDV_{D7.5,CN}$
										Euro I - 91/542/EEC I	$T_{HDV,D7.5,1,EI}$	$HDV_{D7.5,EI}$
										Euro II - 91/542/EEC II	$T_{HDV,D7.5,1,EII}$	$HDV_{D7.5,EII}$
										Euro III - 2000	$T_{HDV,D7.5,1,EIII}$	$HDV_{D7.5,EIII}$
										Euro IV - 2005	$T_{HDV,D7.5,1,EIV}$	$HDV_{D7.5,EIV}$
										Euro V - 2008	$T_{HDV,D7.5,1,EV}$	$HDV_{D7.5,EV}$
										Euro VI	$T_{HDV,D7.5,1,EVI}$	$HDV_{D7.5,EVI}$
				Diesel 7.5t – 16t	HDV_{D16}	-	$U_{HDV,D16}$	-	1	Conventional	$T_{HDV,D16,1,CN}$	$HDV_{D16,CN}$
										Euro I - 91/542/EEC I	$T_{HDV,D16,1,EI}$	$HDV_{D16,EI}$

VEHICLE TYPE (*v*)	VEHICLE TYPE % (V_v)	FUEL TYPE (*f*)	FUEL TYPE % ($F_{v,f}$)	VEHICLE SUB-TYPE (ENGINE CAPACITY CATEGORY OR UNLADEN WEIGHT CATEGORY) (*s*)	VEHICLE SUB-TYPE % (v_s)	ENGINE CAPACITY % ($E_{v,s}$)	UNLADEN WEIGHT % ($U_{v,s}$)	WEIGHTING FACTOR % (W_v)	GROUP NUMBER (*n*)	EURO CLASSIFICATION (*e*)	VEHICLE SUB-TYPE BREAKDOWN BY EURO CLASS % ($T_{v,s,n,e}$)	EURO CLASS % ($v_{s,e}$)
										Euro II - 91/542/EEC II	$T_{HDV,D16,1,EII}$	$HDV_{D16,EII}$
										Euro III - 2000	$T_{HDV,D16,1,EIII}$	$HDV_{D16,EIII}$
										Euro IV - 2005	$T_{HDV,D16,1,EIV}$	$HDV_{D16,EIV}$
										Euro V - 2008	$T_{HDV,D16,1,EV}$	$HDV_{D16,EV}$
										Euro VI	$T_{HDV,D16,1,EVI}$	$HDV_{D16,EVI}$
										Conventional	$T_{HDV,D32,1,CN}$	$HDV_{D32,CN}$
										Euro I - 91/542/EEC I	$T_{HDV,D32,1,EI}$	$HDV_{D32,EI}$
										Euro II - 91/542/EEC II	$T_{HDV,D32,1,EII}$	$HDV_{D32,EII}$
				Diesel 16t – 32t	HDV_{D32}	-	$U_{HDV,D32}$	W_{HDV}	1	Euro III - 2000	$T_{HDV,D32,1,EIII}$	$HDV_{D32,EIII}$
										Euro IV - 2005	$T_{HDV,D32,1,EIV}$	$HDV_{D32,EIV}$
										Euro V - 2008	$T_{HDV,D32,1,EV}$	$HDV_{D32,EV}$
										Euro VI	$T_{HDV,D32,1,EVI}$	$HDV_{D32,EVI}$

VEHICLE TYPE *(v)*	VEHICLE TYPE % *(V_v)*	FUEL TYPE *(f)*	FUEL TYPE % *($F_{v,f}$)*	VEHICLE SUB-TYPE (ENGINE CAPACITY CATEGORY OR UNLADEN WEIGHT CATEGORY) *(s)*	VEHICLE SUB-TYPE % *(v_s)*	ENGINE CAPACITY % *($E_{v,s}$)*	UNLADEN WEIGHT % *($U_{v,s}$)*	WEIGHTING FACTOR % *(W_v)*	GROUP NUMBER *(n)*	EURO CLASSIFICATION *(e)*	VEHICLE SUB-TYPE BREAKDOWN BY EURO CLASS % *($T_{v,s,n,e}$)*	EURO CLASS % *($v_{s,e}$)*
										Conventional	$T_{HDV,DMAX,1,CN}$	$HDV_{DMAX,CN}$
										Euro I - 91/542/EEC I	$T_{HDV,DMAX,1,EI}$	$HDV_{DMAX,EI}$
										Euro II - 91/542/EEC II	$T_{HDV,DMAX,1,EII}$	$HDV_{DMAX,EII}$
				Diesel >32t	HDV_{DMAX}	-	$U_{HDV,DMAX}$	$1 – W_{HDV}$	1	Euro III - 2000	$T_{HDV,DMAX,1,EIII}$	$HDV_{DMAX,EIII}$
										Euro IV - 2005	$T_{HDV,DMAX,1,EIV}$	$HDV_{DMAX,EIV}$
										Euro V - 2008	$T_{HDV,DMAX,1,EV}$	$HDV_{DMAX,EV}$
										Euro VI	$T_{HDV,DMAX,1,EVI}$	$HDV_{DMAX,EVI}$

Table A3: Large Public Service Vehicles (LPSVs) Vehicle Breakdown and Annotations

VEHICLE TYPE (*v*)	VEHICLE TYPE % (V_v)	FUEL TYPE (*f*)	FUEL TYPE % ($F_{v,f}$)	VEHICLE SUB-TYPE (ENGINE CAPACITY CATEGORY OR UNLADEN WEIGHT CATEGORY) (*s*)	VEHICLE SUB-TYPE % (v_s)	ENGINE CAPACITY % ($E_{v,s}$)	UNLADEN WEIGHT % ($U_{v,s}$)	WEIGHTING FACTOR % (W_v)	GROUP NUMBER (*n*)	EURO CLASSIFICATION (*e*)	VEHICLE SUB-TYPE BREAKDOWN BY EURO CLASS % ($T_{v,s,n,e}$)	EURO CLASS % ($v_{s,e}$)
Large Public Service Vehicles (LPSV)	V_{LPSV}	CNG (C)	$F_{LPSV,C}$	Urban CNG Buses	$LPSV_{BC}$	-	-	-	1	Euro I - 91/542/EEC I	$T_{LPSV,BC,1,EI}$	$LPSV_{BC,EI}$
										Euro II - 91/542/EEC II	$T_{LPSV,BC,1,EII}$	$LPSV_{BC,EII}$
										Euro III - 2000	$T_{LPSV,BC,1,EIII}$	$LPSV_{BC,EIII}$
										EEV	$T_{LPSV,BC,1,EEV}$	$LPSV_{BC,EEV}$
		Diesel (D)	$F_{LPSV,D}$	Urban Buses Standard	$LPSV_{BS}$	-	-	W_{LPSV}	1	Conventional	$T_{LPSV,BS,1,CN}$	$LPSV_{BS,CN}$
										Euro I - 91/542/EEC I	$T_{LPSV,BS,1,EI}$	$LPSV_{BS,EI}$
										Euro II - 91/542/EEC II	$T_{LPSV,BS,1,EII}$	$LPSV_{BS,EII}$
										Euro III - 2000	$T_{LPSV,BS,1,EIII}$	$LPSV_{BS,EIII}$
										Euro IV - 2005	$T_{LPSV,BS,1,EIV}$	$LPSV_{BS,EIV}$
										Euro V - 2008	$T_{LPSV,BS,1,EV}$	$LPSV_{BS,EV}$
										Euro VI	$T_{LPSV,BS,1,EVI}$	$LPSV_{BS,EVI}$

VEHICLE TYPE *(v)*	VEHICLE TYPE % *(V_v)*	FUEL TYPE *(f)*	FUEL TYPE % *($F_{v,f}$)*	VEHICLE SUB-TYPE (ENGINE CAPACITY CATEGORY OR UNLADEN WEIGHT CATEGORY) *(s)*	VEHICLE SUB-TYPE % *(v_s)*	ENGINE CAPACITY % *($E_{v,s}$)*	UNLADEN WEIGHT % *($U_{v,s}$)*	WEIGHTING FACTOR % *(W_v)*	GROUP NUMBER *(n)*	EURO CLASSIFICATION *(e)*	VEHICLE SUB-TYPE BREAKDOWN BY EURO CLASS % *($T_{v,s,n,e}$)*	EURO CLASS % *($v_{s,e}$)*
				Buses Coaches Standard	$LPSV_{CS}$	-	-	$1 – W_{LPSV}$	1	Conventional	$T_{LPSV,CS,1,CN}$	$LPSV_{CS,CN}$
										Euro I - 91/542/EEC I	$T_{LPSV,CS,1,EI}$	$LPSV_{CS,EI}$
										Euro II - 91/542/EEC II	$T_{LPSV,CS,1,EII}$	$LPSV_{CS,EII}$
										Euro III - 2000	$T_{LPSV,CS,1,EIII}$	$LPSV_{CS,EIII}$
										Euro IV - 2005	$T_{LPSV,CS,1,EIV}$	$LPSV_{CS,EIV}$
										Euro V - 2008	$T_{LPSV,CS,1,EV}$	$LPSV_{CS,EV}$
										Euro VI	$T_{LPSV,CS,1,EVI}$	$LPSV_{CS,EVI}$

Table A4: Motorcycles (M) Vehicle Breakdown and Annotations

VEHICLE TYPE *(v)*	VEHICLE TYPE % *(V_v)*	FUEL TYPE *(f)*	FUEL TYPE % *($F_{v,f}$)*	VEHICLE SUB-TYPE (ENGINE CAPACITY CATEGORY OR UNLADEN WEIGHT CATEGORY) *(s)*	VEHICLE SUB-TYPE % *(v_s)*	ENGINE CAPACITY % *($E_{v,s}$)*	UNLADEN WEIGHT % *($U_{v,s}$)*	WEIGHTING FACTOR % *(W_v)*	GROUP NUMBER *(n)*	EURO CLASSIFICATION *(e)*	VEHICLE SUB-TYPE BREAKDOWN BY EURO CLASS % *($T_{v,s,n,e}$)*	EURO CLASS % *($v_{s,e}$)*
Motorcycles (M)	V_M	Petrol (P)	$F_{M,P}$	2-Stroke <50cm^3	M_{2S-50}	$E_{M,2S-50}$	-	W_{M1}	1	Conventional	$T_{M,2S-50,1,CN}$	$M_{2S-50,CN}$
										Mop - Euro 1	$T_{M,2S-50,1,E1}$	$M_{2S-50,E1}$
										Mop - Euro 2	$T_{M,2S-50,1,E2}$	$M_{2S-50,E2}$
										Mop - Euro 3 and On	$T_{M,2S-50,1,E3}$	$M_{2S-50,E3}$
				4-Stroke <50cm^3	M_{4S-50}	$E_{M,4S-50}$	-	$1 – W_{M1}$	1	Conventional	$T_{M,4S-50,1,CN}$	$M_{4S-50,CN}$
										Mop - Euro 1	$T_{M,4S-50,1,E1}$	$M_{4S-50,E1}$
										Mop - Euro 2	$T_{M,4S-50,1,E2}$	$M_{4S-50,E2}$
										Mop - Euro 3 and On	$T_{M,4S-50,1,E3}$	$M_{4S-50,E3}$
				2-Stroke >50cm^3	M_{2S-MAX}	$E_{M,2S-MAX}$	-	W_{M2}	1	Conventional	$T_{M,2S-MAX,1,CN}$	$M_{2S-MAX,CN}$

VEHICLE TYPE (v)	VEHICLE TYPE % (V_v)	FUEL TYPE (f)	FUEL TYPE % ($F_{v,f}$)	VEHICLE SUB-TYPE (ENGINE CAPACITY CATEGORY OR UNLADEN WEIGHT CATEGORY) (s)	VEHICLE SUB-TYPE % (v_s)	ENGINE CAPACITY % ($E_{v,s}$)	UNLADEN WEIGHT % ($U_{v,s}$)	WEIGHTING FACTOR % (W_v)	GROUP NUMBER (n)	EURO CLASSIFICATION (e)	VEHICLE SUB-TYPE BREAKDOWN BY EURO CLASS % ($T_{v,s,n,e}$)	EURO CLASS % ($v_{s,e}$)
										Mot - Euro 1	$T_{M,2S-MAX,1,E1}$	$M_{2S-MAX,E1}$
										Mot - Euro 2	$T_{M,2S-MAX,1,E2}$	$M_{2S-MAX,E2}$
										Mot - Euro 3 and On	$T_{M,2S-MAX,1,E3}$	$M_{2S-MAX,E3}$
				4-Stroke <250cm^3	M_{4S-250}	$E_{M,4S-250}$	-	$1 – W_{M2}$	1	Conventional	$T_{M,4S-250,1,CN}$	$M_{4S-250,CN}$
										Mot - Euro 1	$T_{M,4S-250,1,E1}$	$M_{4S-250,E1}$
										Mot - Euro 2	$T_{M,4S-250,1,E2}$	$M_{4S-250,E2}$
										Mot - Euro 3 and On	$T_{M,4S-250,1,E3}$	$M_{4S-250,E3}$
				4-Stroke 250 – 750cm^3	M_{4S-750}	$E_{M,4S-750}$	-	$(1 – W_{M2}) \times W_{M3}$	1	Conventional	$T_{M,4S-750,1,CN}$	$M_{4S-750,CN}$
										Mot - Euro 1	$T_{M,4S-750,1,E1}$	$M_{4S-750,E1}$
										Mot - Euro 2	$T_{M,4S-750,1,E2}$	$M_{4S-750,E2}$

VEHICLE TYPE *(v)*	VEHICLE TYPE % *(V_v)*	FUEL TYPE *(f)*	FUEL TYPE % *($F_{v,f}$)*	VEHICLE SUB-TYPE (ENGINE CAPACITY CATEGORY OR UNLADEN WEIGHT CATEGORY) *(s)*	VEHICLE SUB-TYPE % *(v_s)*	ENGINE CAPACITY % *($E_{v,s}$)*	UNLADEN WEIGHT % *($U_{v,s}$)*	WEIGHTING FACTOR % *(W_v)*	GROUP NUMBER *(n)*	EURO CLASSIFICATION *(e)*	VEHICLE SUB-TYPE BREAKDOWN BY EURO CLASS % *($T_{v,s,n,e}$)*	EURO CLASS % *($v_{s,e}$)*
										Mot - Euro 3 and On	$T_{M,4S-750,1,E3}$	$M_{4S-750,E3}$
				4-Stroke >750cm^3	M_{4S-MAX}	$E_{M,4S-MAX}$	-	$(1 – W_{M2})$ x $(1 – W_{M3})$	1	Conventional	$T_{M,4S-MAX,1,CN}$	$M_{4S-MAX,CN}$
										Mot - Euro 1	$T_{M,4S-MAX,1,E1}$	$M_{4S-MAX,E1}$
										Mot - Euro 2	$T_{M,4S-MAX,1,E2}$	$M_{4S-MAX,E2}$
										Mot - Euro 3 and On	$T_{M,4S-MAX,1,E3}$	$M_{4S-MAX,E3}$

Table A5: Small Public Service Vehicles (SPSVs) Vehicle Breakdown and Annotations

VEHICLE TYPE (*v*)	VEHICLE TYPE % (V_v)	FUEL TYPE (*f*)	FUEL TYPE % ($F_{v,f}$)	VEHICLE SUB-TYPE (ENGINE CAPACITY CATEGORY OR UNLADEN WEIGHT CATEGORY) (*s*)	VEHICLE SUB-TYPE % (v_s)	ENGINE CAPACITY % ($E_{v,s}$)	UNLADEN WEIGHT % ($U_{v,s}$)	WEIGHTING FACTOR % (W_v)	GROUP NUMBER (*n*)	EURO CLASSIFICATION (*e*)	VEHICLE SUB-TYPE BREAKDOWN BY EURO CLASS % ($T_{v,s,n,e}$)	EURO CLASS % ($v_{s,e}$)
Small Public Service Vehicles (SPSV)	V_{SPSV}	Petrol (P)	$F_{SPSV,P}$	Petrol Small (PS)	$SPSV_{PS}$	$E_{SPSV,PS}$	-	-	1	PRE ECE	$T_{SPSV,PS,1,PECE}$	$SPSV_{PS,PECE}$
										ECE 15/00-01	$T_{SPSV,PS,1,ECE1}$	$SPSV_{PS,ECE1}$
										ECE 15/02	$T_{SPSV,PS,1,ECE2}$	$SPSV_{PS,ECE2}$
										ECE 15/03	$T_{SPSV,PS,1,ECE3}$	$SPSV_{PS,ECE3}$
										ECE 15/04	$T_{SPSV,PS,1,ECE4}$	$SPSV_{PS,ECE4}$
										Open Loop (Pre-EEC / Cold Start)	$T_{SPSV,PS,1,OL}$	$SPSV_{PS,OL}$
										Euro 1 - 91/441/EEC	$T_{SPSV,PS,1,E1}$	$SPSV_{PS,E1}$
										Euro 2 - 94/12/EEC	$T_{SPSV,PS,1,E2}$	$SPSV_{PS,E2}$
										Euro 3 - 98/69/EC I	$T_{SPSV,PS,1,E3}$	$SPSV_{PS,E3}$
										Euro 4 - 98/69/EC II	$T_{SPSV,PS,1,E4}$	$SPSV_{PS,E4}$
										Euro 5 - EC 715/2007	$T_{SPSV,PS,1,E5}$	$SPSV_{PS,E5}$

VEHICLE TYPE (v)	VEHICLE TYPE % (V_v)	FUEL TYPE (f)	FUEL TYPE % $(F_{v,f})$	VEHICLE SUB-TYPE (ENGINE CAPACITY CATEGORY OR UNLADEN WEIGHT CATEGORY) (s)	VEHICLE SUB-TYPE % (v_s)	ENGINE CAPACITY % $(E_{v,s})$	UNLADEN WEIGHT % $(U_{v,s})$	WEIGHTING FACTOR % (W_v)	GROUP NUMBER (n)	EURO CLASSIFICATION (e)	VEHICLE SUB-TYPE BREAKDOWN BY EURO CLASS % $(T_{v,s,n,e})$	EURO CLASS % $(v_{s,e})$
										Euro 6 up to 2016	$T_{SPSV,PS,1,E6-2016}$	$SPSV_{PS,E6-2016}$
										Euro 6 2017 - 2019	$T_{SPSV,PS,1,E6-2019}$	$SPSV_{PS,E6-2019}$
				Petrol Medium (PMED)	$SPSV_{PMED}$	$E_{SPSV,PMED}$	-	-	1	PRE ECE	$T_{SPSV,PM,1,PECE}$	$SPSV_{PM,PECE}$
										ECE 15/00-01	$T_{SPSV,PM,1,ECE1}$	$SPSV_{PM,ECE1}$
										ECE 15/02	$T_{SPSV,PM,1,ECE2}$	$SPSV_{PM,ECE2}$
										ECE 15/03	$T_{SPSV,PM,1,ECE3}$	$SPSV_{PM,ECE3}$
										ECE 15/04	$T_{SPSV,PM,1,ECE4}$	$SPSV_{PM,ECE4}$
										Open Loop (Pre-EEC / Cold Start)	$T_{SPSV,PM,1,OL}$	$SPSV_{PM,OL}$
										Euro 1 - 91/441/EEC	$T_{SPSV,PM,1,E1}$	$SPSV_{PM,E1}$
										Euro 2 - 94/12/EEC	$T_{SPSV,PM,1,E2}$	$SPSV_{PM,E2}$
										Euro 3 - 98/69/EC I	$T_{SPSV,PM,1,E3}$	$SPSV_{PM,E3}$
										Euro 4 - 98/69/EC II	$T_{SPSV,PM,1,E4}$	$SPSV_{PM,E4}$

VEHICLE TYPE (*v*)	VEHICLE TYPE % (V_v)	FUEL TYPE (*f*)	FUEL TYPE % ($F_{v,f}$)	VEHICLE SUB-TYPE (ENGINE CAPACITY CATEGORY OR UNLADEN WEIGHT CATEGORY) (*s*)	VEHICLE SUB-TYPE % (v_s)	ENGINE CAPACITY % ($E_{v,s}$)	UNLADEN WEIGHT % ($U_{v,s}$)	WEIGHTING FACTOR % (W_v)	GROUP NUMBER (*n*)	EURO CLASSIFICATION (*e*)	VEHICLE SUB-TYPE BREAKDOWN BY EURO CLASS % ($T_{v,s,n,e}$)	EURO CLASS % ($v_{s,e}$)
										Euro 5 - EC 715/2007	$T_{SPSV,PM,1,E5}$	$SPSV_{PM,E5}$
										Euro 6 up to 2016	$T_{SPSV,PM,1,E6\text{-}2016}$	$SPSV_{PM,E6\text{-}2016}$
										Euro 6 2017 – 2019	$T_{SPSV,PM,1,E6\text{-}2019}$	$SPSV_{PM,E6\text{-}2019}$
				Petrol Large (PL)	$SPSV_{PL}$	$E_{SPSV,PL}$	-	-	1	PRE ECE	$T_{SPSV,PL,1,PECE}$	$SPSV_{PL,PECE}$
										ECE 15/00-01	$T_{SPSV,PL,1,ECE1}$	$SPSV_{PL,ECE1}$
										ECE 15/02	$T_{SPSV,PL,1,ECE2}$	$SPSV_{PL,ECE2}$
										ECE 15/03	$T_{SPSV,PL,1,ECE3}$	$SPSV_{PL,ECE3}$
										ECE 15/04	$T_{SPSV,PL,1,ECE4}$	$SPSV_{PL,ECE4}$
										Euro 1 - 91/441/EEC	$T_{SPSV,PL,1,E1}$	$SPSV_{PL,E1}$
										Euro 2 - 94/12/EEC	$T_{SPSV,PL,1,E2}$	$SPSV_{PL,E2}$
										Euro 3 - 98/69/EC I	$T_{SPSV,PL,1,E3}$	$SPSV_{PL,E3}$

VEHICLE TYPE *(v)*	VEHICLE TYPE % *(V_v)*	FUEL TYPE *(f)*	FUEL TYPE % *($F_{v,f}$)*	VEHICLE SUB-TYPE (ENGINE CAPACITY CATEGORY OR UNLADEN WEIGHT CATEGORY) *(s)*	VEHICLE SUB-TYPE % *(v_s)*	ENGINE CAPACITY % *($E_{v,s}$)*	UNLADEN WEIGHT % *($U_{v,s}$)*	WEIGHTING FACTOR % *(W_v)*	GROUP NUMBER *(n)*	EURO CLASSIFICATION *(e)*	VEHICLE SUB-TYPE BREAKDOWN BY EURO CLASS % *($T_{v,s,n,e}$)*	EURO CLASS % *($v_{s,e}$)*
										Euro 4 - 98/69/EC II	$T_{SPSV,PL,1,E4}$	$SPSV_{PL,E4}$
										Euro 5 - EC 715/2007	$T_{SPSV,PL,1,E5}$	$SPSV_{PL,E5}$
										Euro 6 up to 2016	$T_{SPSV,PL,1,E6-2016}$	$SPSV_{PL,E6-2016}$
										Euro 6 2017 – 2019	$T_{SPSV,PL,1,E6-2019}$	$SPSV_{PL,E6-2019}$
		Diesel (D)	$F_{SPSV,D}$	Diesel Small (DS)	$SPSV_{DS}$	$E_{SPSV,DS}$	-	-	2	Euro 4 - 98/69/EC II	$T_{SPSV,DS,2,E4}$	$SPSV_{DS,E4}$
										Euro 5 - EC 715/2007	$T_{SPSV,DS,2,E5}$	$SPSV_{DS,E5}$
										Euro 6 up to 2016	$T_{SPSV,DS,2,E6-2016}$	$SPSV_{DS,E6-2016}$
										Euro 6 2017 - 2019	$T_{SPSV,DS,2,E6-2019}$	$SPSV_{DS,E6-2019}$
				Diesel Medium (DM)	$SPSV_{DM}$	$E_{SPSV,DM}$	-	-	1	Conventional	$T_{SPSV,DM,1,CN}$	$SPSV_{DM,CN}$
										Euro 1 - 91/441/EEC	$T_{SPSV,DM,1,E1}$	$SPSV_{DM,E1}$

VEHICLE TYPE *(v)*	VEHICLE TYPE % (V_v)	FUEL TYPE *(f)*	FUEL TYPE % $(F_{v,f})$	VEHICLE SUB-TYPE (ENGINE CAPACITY CATEGORY OR UNLADEN WEIGHT CATEGORY) *(s)*	VEHICLE SUB-TYPE % (v_s)	ENGINE CAPACITY % $(E_{v,s})$	UNLADEN WEIGHT % $(U_{v,s})$	WEIGHTING FACTOR % (W_v)	GROUP NUMBER *(n)*	EURO CLASSIFICATION *(e)*	VEHICLE SUB-TYPE BREAKDOWN BY EURO CLASS % $(T_{v,s,n,e})$	EURO CLASS % $(v_{s,e})$
										Euro 2 - 94/12/EEC	$T_{SPSV,DM,1,E2}$	$SPSV_{DM,E2}$
										Euro 3 - 98/69/EC I	$T_{SPSV,DM,1,E3}$	$SPSV_{DM,E3}$
										Euro 4 - 98/69/EC II	$T_{SPSV,DM,1,E4}$	$SPSV_{DM,E4}$
										Euro 5 - EC 715/2007	$T_{SPSV,DM,1,E5}$	$SPSV_{DM,E5}$
										Euro 6 up to 2016	$T_{SPSV,DM,1,E6-2016}$	$SPSV_{DM,E6-2016}$
										Euro 6 2017 - 2019	$T_{SPSV,DM,1,E6-2019}$	$SPSV_{DM,E6-2019}$
				Diesel Large (DL)	$SPSV_{DL}$	$E_{SPSV,DL}$	-	-	1	Conventional	$T_{SPSV,DL,1,CN}$	$SPSV_{DL,CN}$
										Euro 1 - 91/441/EEC	$T_{SPSV,DL,1,E1}$	$SPSV_{DL,E1}$
										Euro 2 - 94/12/EEC	$T_{SPSV,DL,1,E2}$	$SPSV_{DL,E2}$
										Euro 3 - 98/69/EC I	$T_{SPSV,DL,1,E3}$	$SPSV_{DL,E3}$
										Euro 4 - 98/69/EC II	$T_{SPSV,DL,1,E4}$	$SPSV_{DL,E4}$
										Euro 5 - EC 715/2007	$T_{SPSV,DL,1,E5}$	$SPSV_{DL,E5}$

VEHICLE TYPE *(v)*	VEHICLE TYPE % *(V_v)*	FUEL TYPE *(f)*	FUEL TYPE % *($F_{v,f}$)*	VEHICLE SUB-TYPE (ENGINE CAPACITY CATEGORY OR UNLADEN WEIGHT CATEGORY) *(s)*	VEHICLE SUB-TYPE % *(v_s)*	ENGINE CAPACITY % *($E_{v,s}$)*	UNLADEN WEIGHT % *($U_{v,s}$)*	WEIGHTING FACTOR % *(W_v)*	GROUP NUMBER *(n)*	EURO CLASSIFICATION *(e)*	VEHICLE SUB-TYPE BREAKDOWN BY EURO CLASS % *($T_{v,s,n,e}$)*	EURO CLASS % *($v_{s,e}$)*
										Euro 6 up to 2016	$T_{SPSV,DL,1,E6\text{-}2016}$	$SPSV_{DL,E6\text{-}2016}$
										Euro 6 2017 - 2019	$T_{SPSV,DL,1,E6\text{-}2019}$	$SPSV_{DL,E6\text{-}2019}$
		Hybrid Petrol (H)	$F_{SPSV,H}$	Hybrid Petrol Small (HPS)	$SPSV_{HPS}$	-	-	-	2	Euro 4 and Later	$T_{SPSV,HPS,2,E4\&L}$	$SPSV_{HPS,E4\&L}$
				Hybrid Petrol Medium (HPM)	$SPSV_{HPM}$					Euro 4 and Later	$T_{SPSV,HPM,2,E4\&L}$	$SPSV_{HPM,E4\&L}$
				Hybrid Petrol Large (HPL)	$SPSV_{HPL}$					Euro 4 and Later	$T_{SPSV,HPL,2,E4\&L}$	$SPSV_{HPL,E4\&L}$
		E85 (E)	$F_{SPSV,E}$	Ethanol E85	$SPSV_E$	-	-	-	2	Euro 4	$T_{SPSV,E,2,E4}$	$SPSV_{E,E4}$
										Euro 5	$T_{SPSV,E,2,E5}$	$SPSV_{E,E5}$
										Euro 6	$T_{SPSV,E,2,E6}$	$SPSV_{E,E6}$

Appendix B

Appendix B: Publications

Journal:

Carthy, P; Ó Domhnaill, A; O'Mahony, M; Nolan, A; Moriarty, F; Broderick, B; Hennessy, M; Donnelly, A; Naughton, O & Lyons, S. (2020) Local NO_2 Concentrations and Asthma Among Over-50s in Ireland: A Microdata Analysis. *International Journal of Epidemiology*, *49*(6), 1899–1908. https://doi.org/10.1093/ije/dyaa074

Conference:

Hurley, E; Ó Domhnaill, A; Broderick, B; Hennessy, M & O'Mahony, M. (2021) Examining the Association of $PM_{2.5}$ and NO_2 with the Rate of Dispensing of Respiratory Items. *Society of Social Medicine and Population Health Conference*

Appendix C

Appendix C: PCRS Analysis

Details of the work carried out on the air pollution data are contained in Section C1 and the results of the statistical analysis linking the Medical Card (GMS) prescription data and the environmental data are provided in Section C2.

C1. Environmental Data Analysis

Pollution data was sourced from the Environmental Protection Agency (EPA) website in hourly format and were adjusted to calculate the monthly mean values for every month between September 2014 and December 2016, which matched the extent of the PCRS prescription data. This was collected for both NO_2 and $PM_{2.5}$ to determine if any of the pollutants achieved results which were independent of the other pollutant. The areas selected for the PCRS analysis were South Dublin, North Cork, Dublin North and Dublin North West.

Pollution data was difficult to match with these locations as no monitoring was being carried on one, or both pollutants in some instances, on the areas being analysed. Therefore a number of substitute monitoring data had to be used, as shown in Table C1, which was selected based on the environmental factors which best matched the area being analysed. Dublin North had a monitoring station for both pollutants, with NO_2 being recorded in Swords and $PM_{2.5}$ recorded in Fingal. Dublin North West had an NO_2 monitoring station in Blanchardstown, but the Fingal $PM_{2.5}$ data was used as a substitute in this instance, as it was located close to the area being analysed. South Dublin also had an NO_2 monitoring station, located in Dun Laoghaire but $PM_{2.5}$ data from a Wicklow / Bray monitoring station had to be used as a substitute, again due to its proximity to the study area. Decision making in relation to the North Cork scenario is described in further detail below.

Table C1: $PM_{2.5}$ and NO_2 Monitoring Data Used in PCRS Analysis

PCRS Region	$PM_{2.5}$ Data Used	NO_2 Data Used
South Dublin	Wicklow / Bray*	Dun Laoghaire
North Cork 1	Longford*	Kilkitt, Monaghan*
North Cork 2	Longford*	Portlaoise*
Dublin North	Fingal	Swords
Dublin North West	Fingal*	Blanchardstown

* Monitoring station is a substitute as there is no monitoring station located within PCRS region

The North Cork analysis proved more difficult as there was no $PM_{2.5}$ or NO_2 data available, and neither was there a monitoring station in close proximity to the area. The varied environment in North Cork made it difficult to select a suitable substitute as there is a mix of large rural areas and small towns with high trafficked national routes in the constituency.

Mallow was the only location identified in the PCRS data but a number of other unknown towns / locations were included in the North Cork region. Figure C1 shows that the N20 route aligns to the west of Mallow town, which is the largest populated town in North Cork with a total population of 13408, accounting for both the urban and rural electoral districts of Mallow (Central Statistics Office, 2022). This represented approximately 15% of the total population in the area of North Cork shown in Figure C1. Another 11% of the population of North Cork were located in electoral districts through which the N20 national route passes. The M8 motorway passes through a number of electoral districts in the northeast of County Cork and a further 21% of the population were located in these districts.

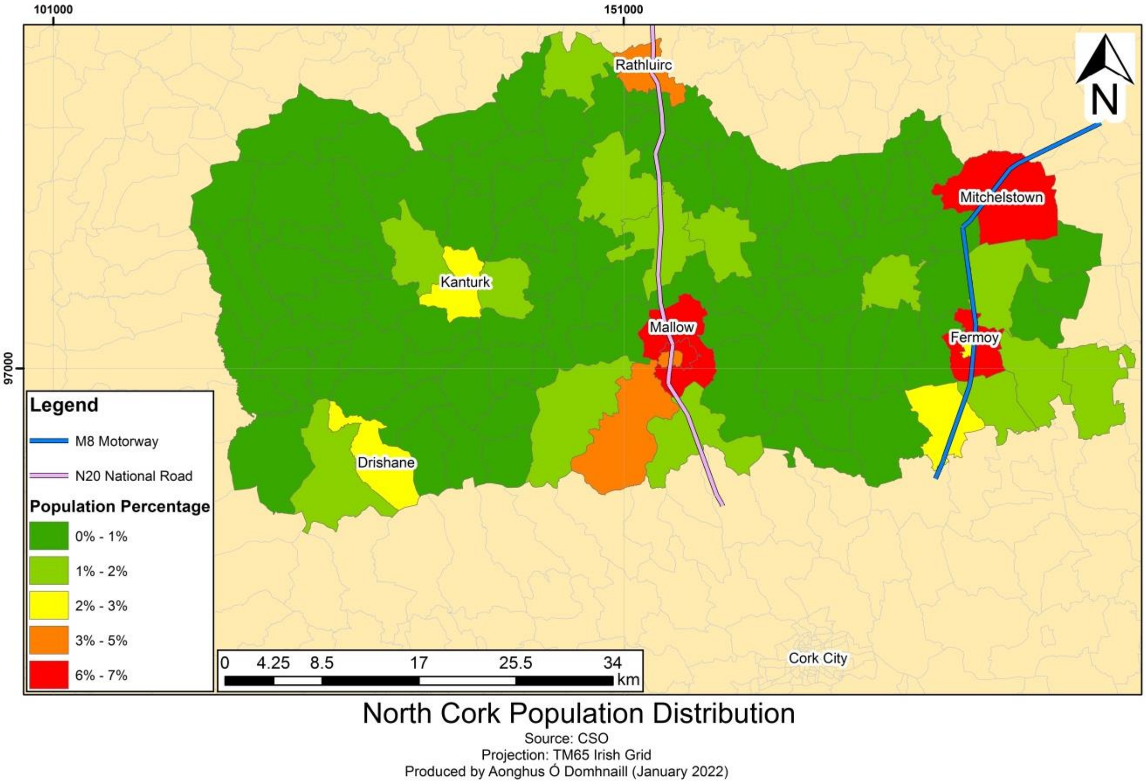

Figure C1: North Cork Population Distribution and Major Routes

The high proportion of the North Cork population which were located close to a national route highlighted the need to identify an EPA monitoring station location which also experienced similar traffic conditions and as Mallow was the only location identified in the PCRS data, it was decided to focus on matching the traffic conditions of the N20 route at Mallow town. The Average Daily Traffic (ADT) data on the N20 at Mallow was unknown as there was no Transport Infrastructure Ireland traffic counters on the N20 at the town, but was estimated by finding the average (shown in Table C4) of two counters, one south of the town between Blarney and Mallow (shown in Table C2) and one north of the town, between Buttevant and Charleville (shown in Table C3) (Transport Infrastructure Ireland, 2022).

Table C2: N20 South of Mallow Traffic - Between Blarney and Mallow (Transport Infrastructure Ireland, 2022)

Year	ADT	% HGV	Coverage
2022	12205	6.30%	2%
2021	14542	7.60%	100%
2020	13260	8%	100%
2019	17631	6.30%	92.10%
2018	17080	6.30%	99.70%
2017	16822	6.10%	99.70%

Year	ADT	% HGV	Coverage
2016	15332	6.20%	99.70%
2015	16138	5.90%	99.70%
2014	16088	5.90%	99.70%
2013	15798	5.90%	83.50%

Table C3: N20 North of Mallow Traffic - Between Charleville and Buttevant (Transport Infrastructure Ireland, 2022)

Year	ADT	% HGV	Coverage
2022	7315	8.80%	2%
2021	8961	9.30%	100%
2020	8162	10%	100%
2019	10656	7.70%	94.80%
2018	10479	7.90%	99.70%
2017	10322	7.60%	99.70%
2016	9764	7.50%	99.70%
2015	9757	7.30%	99.70%
2014	9957	7.50%	99.70%
2013	9902	7.70%	83.50%

Table C4: Average N20 Mallow Traffic

Year	ADT	% HGV	Coverage
2022	9760	7.55%	2%
2021	11751.5	8.45%	100.00%
2020	10711	8.95%	100.00%
2019	14143.5	7.00%	93.45%
2018	13779.5	7.10%	99.70%
2017	13572	6.85%	99.70%
2016	12548	6.85%	99.70%
2015	12947.5	6.60%	99.70%
2014	13022.5	6.70%	99.70%
2013	12850	6.80%	83.50%

Once the traffic conditions for the N20 at Mallow were calculated, the next step was to identify all the locations of NO_2 and $PM_{2.5}$ EPA monitoring stations and to determine which locations best matched the conditions experienced in Mallow. The monitoring station at Longford town was the best match for a $PM_{2.5}$ scenario, as it was an inland location, with the population of the Longford Town rural and urban electoral districts at 10325, similar to Mallow and the N4 route in close proximity bypassing the town (Central Statistics Office, 2022) (Transport Infrastructure Ireland, 2022). Traffic conditions were similar to those calculated for Mallow Town as shown in Table C5. The ADT was slightly lower on the N4 route with differences ranging between 648 and 2491 from 2013 onwards. The percentage of HGVs was slightly higher on the N4 route but this counteracted the lower ADT and resulted in the HGV numbers being similar on both routes, with only differences of between 2 and 96 more HGVs on the N4 compared to the N20 at Mallow.

Table C5: N4 Longford Town East - Between Dublin Road and Granard Road Roundabouts (Transport Infrastructure Ireland, 2022)

Year	ADT	% HGV	Coverage
2022	9112	8.80%	2%
2021	10893	10.00%	100.00%
2020	9319	11.00%	100.00%
2019	12377	8.50%	90.20%
2018	12136	8.60%	99.70%
2017	12103	8.20%	99.70%
2016	11657	8.20%	99.70%
2015	11085	8.20%	99.70%
2014	10531	8.30%	99.70%
2013	10544	8.40%	83.50%

In terms of the NO_2 data, three locations (Enniscorthy, Kilkenny and Portlaoise) were considered for comparison to Mallow based on the availability of EPA monitoring data during the PCRS data period (2014 to 2016). A number of conditions were considered to determine the best location to use as a substitute for Mallow in this analysis, which included population, transport services, proximity to coast, weather conditions, land use and major transport routes. Table C6 shows details of each of these parameters for each of the towns / monitoring station locations considered.

The population comparison was based on the population of the urban and rural CSO electoral districts of the respective towns. This showed that the numbers for Mallow and Enniscorthy were similar whilst the population of Portlaoise was approximately 6500 more than Mallow and the population of Kilkenny was over double that of Mallow.

The town of Mallow has a train station which is regularly serviced by the Cork to Dublin route. Trains can be a unique source of NO_2 and therefore was included as part of the criteria when selecting a suitable substitute for Mallow Town. All of the towns had a train service and therefore passed this criterion.

The next parameter considered was the proximity of the towns to the coastline in comparison to Mallow as this could have an impact on the air quality at a specific location, with potentially less pollutants from offshore winds than inland winds. The town of Mallow is approximately 50km from the nearest coastline whilst Enniscorthy was only approximately 20km from the coast, which potentially could result in varying air quality conditions in comparison to those experienced in Mallow. The towns of Kilkenny and Portlaoise were 70 and 80km respectively from the coastline, which highlighted that offshore wind effects on air quality would be less than those in Enniscorthy and would be closer to those experienced in Mallow.

The main land use categories within the town of Mallow were continuous urban, discontinuous urban, green urban and industrial (located on the boundary of the town). Land use classifications within Kilkenny matched this criterion, whilst there were no green urban areas in either Enniscorthy or Portlaoise and the industrial area within Portlaoise was more centrally located than the other towns.

The weather conditions were considered in combination with the major routes to determine the scenario which best reflects the conditions in Mallow. The N20 to the west of Mallow town has an ADT of approximately 13000 vehicles and is situated more than 0.5km from the town centre on the predominant wind direction side of the town. The Enniscorthy scenario was significantly different as the N11 major route passed directly through the town centre and therefore the distribution of pollutants by the predominant wind direction would potentially disperse over half of the town. The Kilkenny scenario was also significantly different from the Mallow scenario as the major route was a circular road scenario which surrounds two thirds of the town as shown in Figure C2. Due to the major route surrounding a significant proportion of the town the effects of pollution from the major route would be experienced for longer periods of the year. The Portlaoise scenario was the most similar to Mallow despite the larger ADT and higher percentage of HGVs, as the route aligned to one side of the town and similar to Mallow was on the predominant wide direction side of the town. The route was located further from Portlaoise town centre (>2.2km) in comparison to Mallow, which was >0.5km from the town centre. This could offset part of the additional pollutants that would be expected to be produced by the larger

ADT and increased percentage of HGVs on the Portlaoise route as the distance the pollutants would have to travel to the town centre would be further from the source.

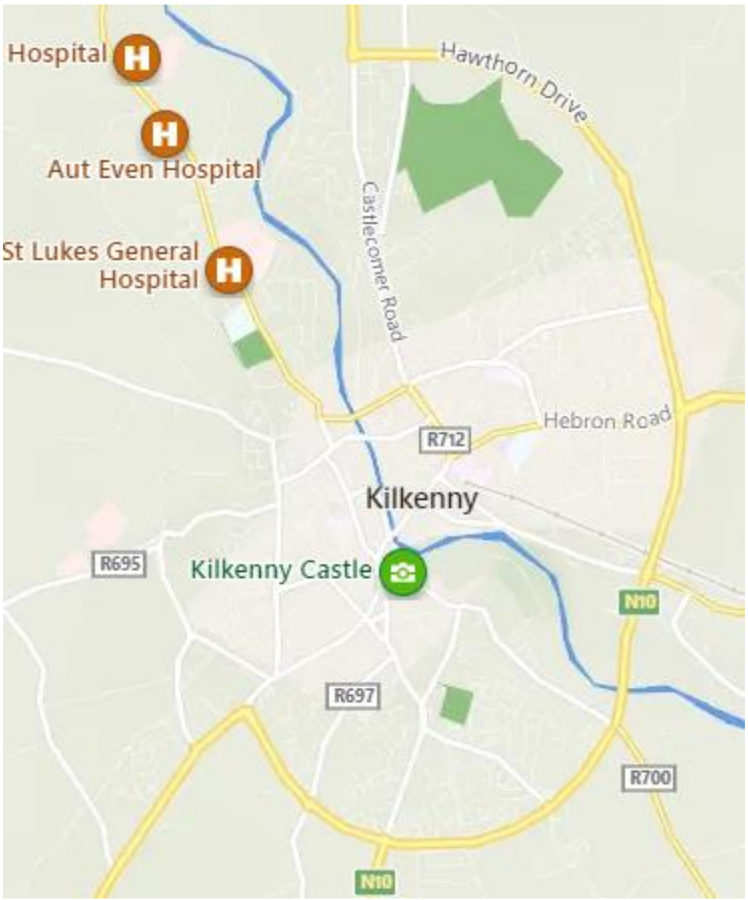

Figure C2: Kilkenny Major Route Scenario – N10 / N76 / N77 Circular Road (Bing Maps, 2022)

Table C6: EPA Monitoring Station Location Comparison to Mallow Town Conditions

Town	Population	Train Service	Proximity to Coast (km)	Weather Conditions	Town Land Use	Major Route(s) Details
Mallow	13408	Yes	50	0.12mm/hr Precipitation 10.2°C Temperature 83.6% Relative Humidity West (Predominant Wind Direction) (20%) 3.4 to 4.8m/s Wind Speeds	Continuous Urban Area Discontinuous Urban Area Green Urban Area Industrial (Town Boundary)	Located West of Town (Predominant Wind Side) >0.5km from Town Centre ~13000 ADT ~7% HGV
Enniscorthy	12651	Yes	20	0.1mm/hr Precipitation 10.2°C Temperature 83.8% Relative Humidity Southwest (Predominant Wind Direction) (23%) 3.1 to 5m/s Wind Speeds	Continuous Urban Area Discontinuous Urban Area No Green Urban Area Industrial (Town Boundary)	Passes Directly through Town Centre 0km from Town Centre ~14000 ADT ~5.7% HGV
Kilkenny	27718	Yes	70	0.1mm/hr Precipitation 10.0°C Temperature 84.2% Relative Humidity South (Predominant Wind Direction) (22%) 2.6 to 4.7m/s Wind Speeds	Continuous Urban Area Discontinuous Urban Area Green Urban Industrial (Town Boundary)	Circular Route around 2/3 of Town >1.3km from Town Centre ~9000 ADT ~4% HGV

Town	Population	Train Service	Proximity to Coast (km)	Weather Conditions	Town Land Use	Major Route(s) Details
Portlaoise	19983	Yes	80	0.1 mm/hr Precipitation 9.7°C Temperature 84.3% Relative Humidity South (Predominant Wind Direction) (23%) 2.2 to 4.3m/s Wind Speeds	Continuous Urban Area Discontinuous Urban Area No Green Urban Area Industrial	Located South of Town (Predominant Wind Side) >2.2km away ~25000 AADT ~10% HGV

Therefore, for one North Cork scenario, the $PM_{2.5}$ data for Longford and the NO_2 data for Portlaoise were used. Figure C1 above, shows large rural areas which are less populated surrounding the Mallow electoral districts and in the North Cork region, which have little or no major / heavily trafficked routes and therefore a separate scenario for North Cork was considered. In terms of $PM_{2.5}$ data, there was no rural monitoring station location available to use as a substitute, therefore, the Longford data was retained for this scenario. There was one monitoring station for NO_2 data which mainly reflected a rural environment, which was the station at Kilkitt, Monaghan. Therefore the Kilkitt NO_2 data was used in combination with the $PM_{2.5}$ of Longford for a separate North Cork scenario.

Figure C3 and Figure C4 show the levels of NO_2 and $PM_{2.5}$ recorded at the selected monitoring stations from January 2014 to December 2016. Air pollution data was not collected for a number of months in the first half of 2014 for all $PM_{2.5}$ stations and the NO_2 Portlaoise station, but this did not affect the analysis as the PCRS data was only available from September 2014 to December 2016. The monitoring station at Dún Laoghaire was inactive between October and December 2014 and the station at Bray, Wicklow was inactive between July and September 2016. Figure C3 and Figure C4 show that the air pollution trends in each of the regions were significantly different which provided a better mix of data for the statistical analysis linking air pollution exposure to prescribing rates.

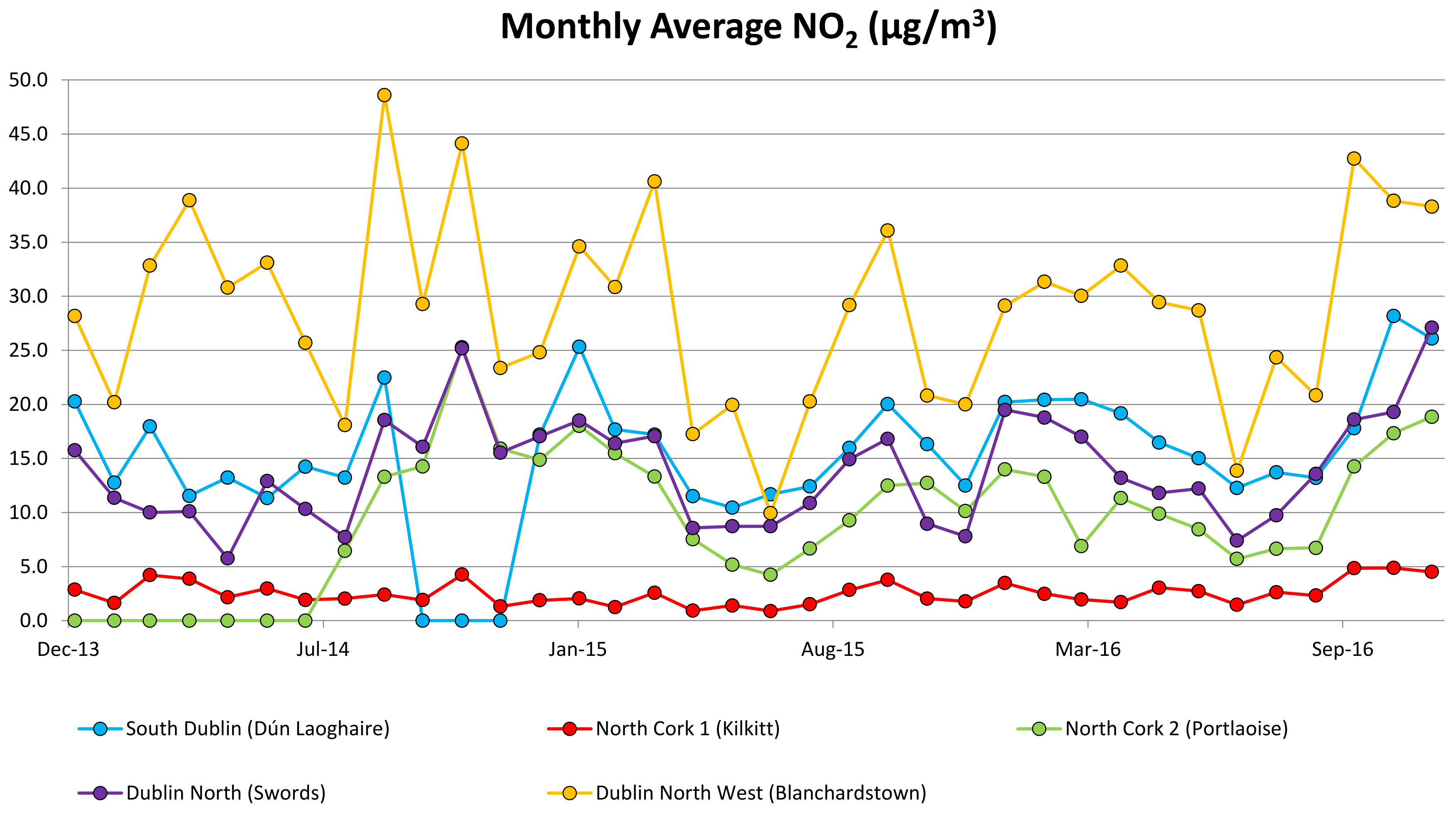

Figure C3: NO_2 Concentration Levels at Selected Monitoring Stations 2014 – 2016

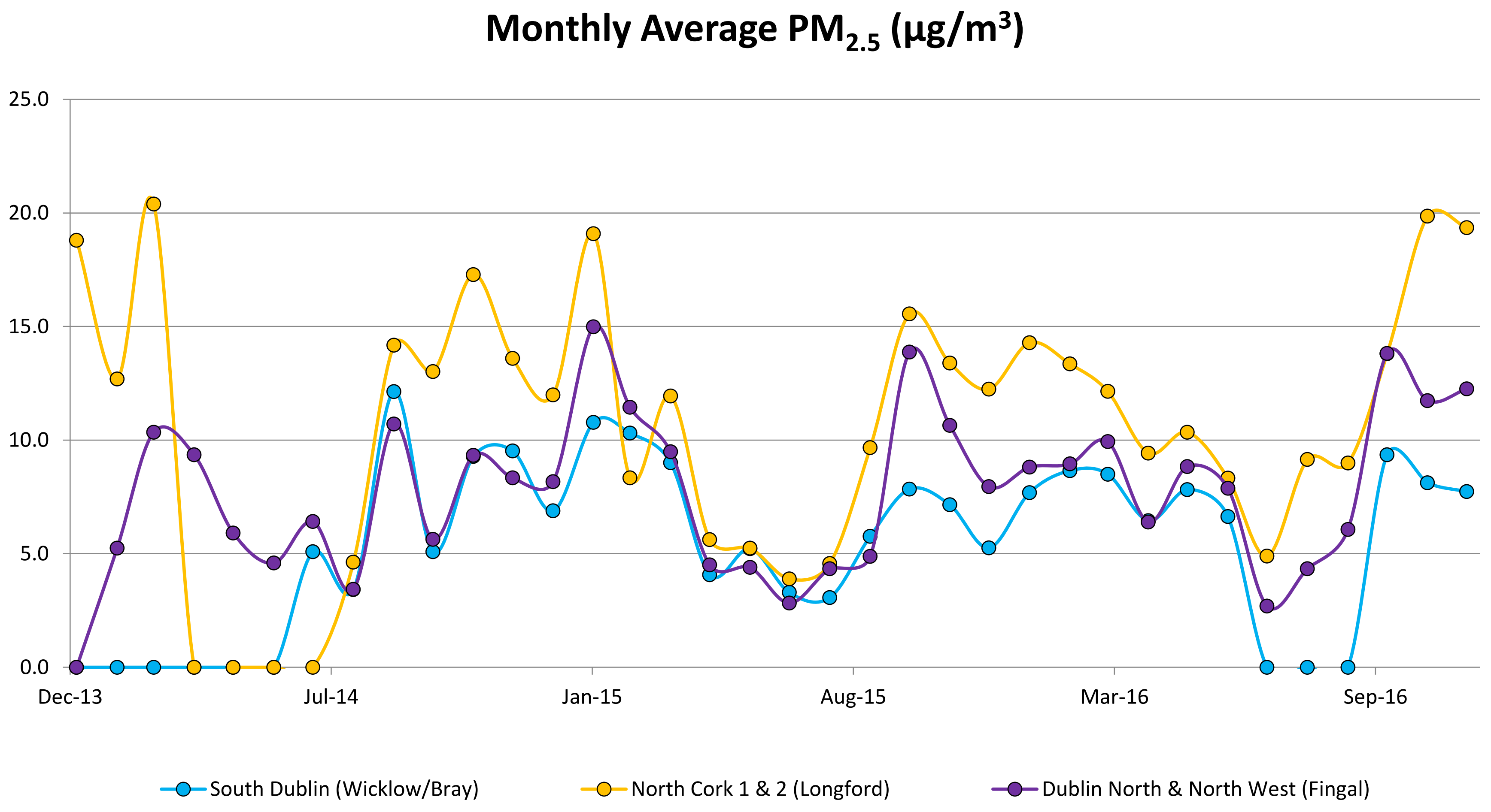

Figure C4: $PM_{2.5}$ Concentration Levels at Selected Monitoring Stations 2014 - 2016

C2. Results of PCRS Analysis

The PCRS analysis described below was written and carried out on the Medical Card (GMS) prescription data by Eimir Hurley, a PhD scholar in the Centre for Health Policy and Management of Trinity College Dublin, which was collated in monthly logs from September 2014 to December 2016. This prescribing data was available for all age groups within all constituencies in Ireland but areas and groups of the population were selected for the analysis based on their unique prescribing trends. This analysis focused on the prescribing of medication which is used to treat or contain respiratory health issues. In winter, it is commonly expected for respiratory medication prescribing to increase, therefore, as part of the analysis a winter variable was added to the analysis, which analysed the November to February period against the rest of the year. This could also be used to further strengthen any results achieved for either pollutant as any effects would be independent of winter effects.

Research question. What is the association of PM2.5 and NO2 with the rate of dispensing of respiratory items, adjusting for the influence of seasonality on dispensing patterns

Region	LHO	Area	PM 2.5 reading	NO2
South Dublin	1	Dún Laoghaire, Booterstown, Blackrock, Dún Laoghaire, Monkstown, Stillorgan, Sallynoggin, Dalkey, Foxrock, Killiney, Cabinteely, Shankill, & Loughlinstown	Wicklow/Bray	Dun Laoghaire
North Cork 1	28	Mallow & ?	Longford	Monaghan/ Kilkitt
North Cork 2	28	Mallow & ?	Longford	Portloaise
Dublin North	12	Balbriggan, The Naul, Skerries, Garristown, Oldtown, Lusk, Ballyboghill, Rush, Swords, Malahide, Portmarnock, Darndale, Baldoyle, Coolock, Raheny, Artane and Howth,	Fingal	Swords
Dublin North West	10	Blanchardstown Dublin 7, 11 and 15	Fingal	Blanch

NO2 - transport - elements of agriculture - e.g. slurry- mainly transport though Pm 2.5 - particulate matter -includes pollen - coal and - turf burning - wood

Most interested in NO2 -- Analyse for Pm2.5 - -issue of confounding by one another

Methodology

Data sources:

1. Monthly GMS dispensing data from Sept 2014 to Dec 2016 for four distinct local health areas.

2. GMS eligibility data over the same period

3. Daily EPA levels of PM2.5 and NO2 used to provide a **mean monthly value**

Outcomes assessed :

1) Monthly prevalence of patients dispensed a respiratory item[1] (defined as a patient that received at least one dispensing of a respiratory item in that month)
2) Monthly rate of dispensing of respiratory items to the GMS eligible population
3) Monthly prevalence of patients dispensed an oral steroid[2](defined as a patient that received at least one dispensing of an oral steroid in that month)
4) Monthly rate of dispensing of oral steroid items to the GMS eligible population
5) Monthly prevalence of patients dispensed a short acting bronchodilator[3](defined as a patient that received at least one dispensing of an short acting bronchodilator in that month)
6) Monthly rate of dispensing of short acting bronchodilator items to the GMS eligible population

All models were age adjusted for age, using the 11 different age categories , and winter, defined as November- Feb inclusive.

[1] See appendix for list of respiratory items used in the analysis

[2] Oral steroids -(e.g., prednisolone) = 'rescue medication' - usually a 3-5 day course to reduce an immune response, such as asthma or COPD exacerbation. Note: not exclusively used for respiratory disease - also used for allergic reactions, autoimmune disease etc. However the majority of dispensings of oral steroids would be for respiratory symptoms.

[3]Short acting bronchodilator- (eg, salbutamol = ventolin- blue one), used for symptomatic control of asthma and COPD. It’s the mainstay of therapy in COPD and asthma along with other medications, but also used as a rescue medication for exacerbations of these conditions.

Statistical analysis

Negative binomial regression with count data was used to estimate the association between the variables of interest (PM2.5 and NO2) with the above outcomes, adjusting for the seasonal nature of the dispensing data. The number of patients with GMS eligibility In that month per age group in the relevant area (LHO) was used as an offset.

A sub group analysis was undertaken for each of the outcomes restricting the cohort to children aged 0-4 years only

A sensitivity analysis was undertaken limiting the data to non-winter months only, (i.e. March to Oct inclusive) to examine whether the association between PM2.5 or NO2 and outcome of interest was sufficiently estimated in the full model which adjusted for winter months.

(And yes, the association was the same between the exposure (PM2.5 and NO2) in the non-winter months, which is what you would hope for. So we can say that regardless of whether its winter or non-winter, there was an association between PM2.5 and some of the outcomes investigated).

Interpreting model output

IRR = Incidence rate ratio, is a ratio of two incidence rates.

This is the estimated rate ratio for a one unit increase in the variable of interest, given the other variables are held constant in the model.

So for example if the IRR for PM2.5 was 1.04, this means that if PM 2.5 were to increase by one unit, the outcome of interest would be expected to increase by a factor of 1.04 (or 4%), while holding all other variables in the model constant.

(Our outcomes are all rates - they are either (i) count of patients dispensed to/ GMS eligible population or count of items dispensed/GMS eligible population. So interpreting the model output depending on which outcome you are referring to is

'We would expect (i) the prevalence of patients dispensed a respiratory item, or (ii) the rate of dispensing of respiratory items to increase by a factor of 1.04 or 4% for every unit increase in PM2.5.'

Summary

Winter was the variable with the strongest association with the outcomes and this was most pronounced in the analyses undertaken on the 0-4 year age category.

For most of the outcomes investigated, there was no association between the levels of NO2 and the outcome of interest.

In most regions, there was an association with PM2.5 and the outcome of interest, accounting for the impact of winter on dispensing. This was most pronounced with oral steroids and especially in the sub-group analyses undertake in the 0-4 age group.

Adjusting for the influence of winter on dispensing, for every one unit increase in PM2.5 there was:

- an increase in the prevalence of patients dispensed a respiratory item and the rate of dispensing of respiratory items of the order of 1% in North Cork and Dublin Northwest
  (Table 1 and Table 2)
- an increase in the prevalence of children (0-4 years) dispensed a respiratory item and the rate of dispensing of respiratory items to children (0-4 years) of the order of 3 - 5% in North Cork, Dublin North and Dublin Northwest (Table 3 and Table 4)
- an increase in the prevalence of patients dispensed an oral steroid and the rate of dispensing of oral steroids of the order of 1-3% in North Cork, Dublin North and Dublin Northwest (Table 5 and Table 6)
- an increase in the prevalence of children (0-4 years) dispensed an oral steroid and the rate of dispensing of oral steroid items to children (0-4 years) of the order of 6-8% in North Cork, Dublin North and Dublin Northwest (Table 7 and Table 8)
- an increase in the prevalence of patients dispensed a short acting bronchodilator and the rate of dispensing of short acting bronchodilator items of the order of 1-2% in North Cork, and Dublin Northwest (Table 9 and Table 10)
- an increase in the prevalence of children (0-4 years) dispensed a short acting bronchodilator and the rate of dispensing of short acting bronchodilator items to children (0-4 years) of the order of 4-5% in North Cork, Dublin North and Dublin Northwest (Table 11 and Table 12)

Table 1. Age adjusted incidence rate ratio for the prevalence of patients dispensed a respiratory item

	PM25_Monthly_ Average	NO2_Monthly_ Average	Winter
South Dublin	Model did not converge		
North Cork 1	**1.01***	1.01	**1.08***
North Cork 2	**1.01***	**0.99***	**1.08***
Dublin North	1.00	1.00	**1.05***
Dublin North West	**1.01***	1.00	**1.06***

* Statistically significant association using p-value <0.05 in red.

Table 2. Age adjusted incidence rate ratio for the rate of dispensing of respiratory items

	PM25_Monthly_ Average	NO2_Monthly_ Average	Winter
South Dublin	1.00	1.00	**1.03***
North Cork 1	**1.01***	1.01	**1.07***
North Cork 2	**1.01***	**0.99***	**1.08***
Dublin North	1.00	1.00	**1.05***
Dublin North West	**1.01***	1.00	**1.05***

Table 1 estimates the association between the variables of interest (PM2.5, NO2 and winter) with the outcome of interest = prevalence of patients dispensed a respiratory item , i.e. the number of patients dispensed a respiratory item/ number of GMS eligible patients in that month. Table 2 estimates the association between the variables of interest with the outcome of interest = rate of dispensing of respiratory items, i.e. the number of respiratory items dispensed/ number of GMS eligible patients in that month.

Winter has the strongest association with outcome, in that the prevalence of patients dispensed a resp item increases by 5-8% in winter (November to February) compared with the rest of the year. Similarly the rate of dispensing of respiratory items increases by 3 to 8%.

For every one unit increase in PM2.5, the prevalence of patients dispensed a respiratory item increases by a factor of 1.01 (1%) in North Cork and North West Dublin, adjusting for the impact of winter. Similarly the rate of dispensing of respiratory items increases by the same factor. There is no association between NO2 and either outcome, and when one uses the Portlaoise value of NO2 as a proxy for North Cork (North Cork 2) there is a negative association, in that prevalence of resp patients and rate of dispensing of resp items decreases by 1% with an one unit increase in NO2. How good a proxy for North Cork NO2 is the Portlaoise value?

Table 3. Incidence rate ratio for the prevalence of children (0-4 years) dispensed a respiratory item

	PM25_Monthly_ Average	**NO2_Monthly_ Average**	**Winter**
South Dublin	1.03	1.01	**1.26***
North Cork 1	1.03	1.00	**1.41***
North Cork 2	**1.03***	0.99	**1.44***
Dublin North	**1.04***	1.00	**1.34***
Dublin North West	**1.05***	1.00	**1.32***

(Smaller sample size- just uses one information from one age group as opposed to the full analyses which uses data from all age categories, hence even though you see larger IRR with the Pm2.5, not all these reach statistical significance as the confidence intervals of the effect estimate are wider).

Table 4. Incidence rate ratio for the rate of dispensing of respiratory items to children aged 0-4 years

	PM25_Monthly_Average	NO2_Monthly_Average	Winter
South Dublin	1.04	1.02	**1.26***
North Cork 1	1.03	0.97	**1.34***
North Cork 2	**1.04***	0.99	**1.39***
Dublin North	**1.03***	1.00	**1.33***
Dublin North West	**1.05***	1.00	**1.26***

This is the same analysis as Table 1 and Table 2, restricting to children aged 0-4 years only. There is a much greater association with winter and both outcomes. In the winter season (Nov- Feb) the prevalence of children dispensed a respiratory item is 1.26 to 1.44 times (26% to 44%) greater than in the non-winter period. Similarly the rate of dispensing of respiratory items (the number of resp items dispensed/numbers eligible) is 1.26 to 1.39 times (26% to 39% higher) in the winter period than in the non-winter period.

In Dublin North, with every one unit increase in PM2.5, there is an increase in the prevalence of children (0-4 years) dispensed a respiratory item of 4% adjusting for the impact of winter. There is an increase in the rate of dispensing of respiratory items to children (0-4 years) of 3% .

In Dublin North West, with every one unit increase in Pm2.5, there is an increase in the prevalence of children (0-4 years) dispensed a respiratory item and in the rate of dispensing of respiratory items dispensed to children (0-4 years) of 5% adjusting for the impact of winter.

North Cork gives mixed results depending on which NO2 level is used. South Dublin there is no association of PM2.5 and either outcome.

Table 5. Age adjusted incidence rate ratio for the prevalence of patients dispensed an oral steroid

	PM25_Monthly_Average	NO2_Monthly_Average	Winter
South Dublin	1.01	1.00	**1.14***
North Cork 1	**1.02***	1.01	**1.18***
North Cork 2	**1.03***	**0.99***	**1.20***
Dublin North	**1.01***	1.00	**1.15***
Dublin North West	**1.02***	1.00	**1.15***

Table 6. Age adjusted incidence rate ratio for the rate of dispensing of oral steroid items

	PM25_Monthly_Average	NO2_Monthly_Average	Winter
South Dublin	1.01	1.00	**1.14***
North Cork 1	**1.02***	1.01	**1.19***
North Cork 2	**1.03***	**0.99***	**1.22***
Dublin North	**1.01***	1.00	**1.14***
Dublin North West	**1.02***	1.00	**1.14***

Table 5 estimates the association between the variables of interest (PM2.5, NO2 and winter) with the outcome of interest = prevalence of patients dispensed an oral steroid , i.e. the number of patients dispensed an oral steroid / number of GMS eligible patients in that month. Table 6 estimates the association between the variables of interest with the outcome of interest = rate of dispensing of oral steroid items, i.e. the number of oral steroid items dispensed/ number of GMS eligible patients in that month.

Again, winter has the strongest association with outcome, in that the prevalence of patients dispensed an oral steroid increases by 14-20% in winter (November to February) compared with the rest of the year. Similarly the rate of dispensing increases by 14 to 22%.

For every one unit increase in PM2.5, the prevalence of patients dispensed an oral steroid increases by a factor of 1.01 to 1.03 (1%-3%) depending on which region, adjusting for the impact of winter. Similar increases are observed in the rate of dispensing of oral steroid items.

There is no association between NO2 and either outcome, and when one uses the Portlaoise value of NO2 as a proxy for North Cork (North Cork 2) a negative association is observed.

Table 7. Incidence rate ratio for the prevalence of children (0-4 years) dispensed an oral steroid

	PM25_Monthly_ Average	NO2_Monthly_ Average	Winter
South Dublin	1.04	1.00	**1.70***
North Cork 1	**1.06***	1.01	**1.42***
North Cork 2	**1.08***	0.98	**1.47***
Dublin North	**1.07***	1.00	**1.47***
Dublin North West	**1.07***	1.00	**1.44***

(Smaller sample size- just uses one information from one age group as opposed to the full analyses which uses data from all age categories, hence even though you see larger IRR with the Pm2.5, not all these reach statistical significance as the confidence intervals of the effect estimate are wider).

Table 8. Incidence rate ratio for the rate of dispensing of oral steroid items to children aged 0-4 years

	PM25_Monthly_	NO2_Monthly_	Winter

	Average	Average	
South Dublin	1.05	1.00	**1.75***
North Cork 1	**1.06***	1.01	**1.45***
North Cork 2	**1.08***	0.98	**1.49***
Dublin North	**1.07***	1.00	**1.45***
Dublin North West	**1.07***	1.00	**1.42***

This is the same analysis as Table 5 and Table 6 , this time restricting to children aged 0-4 years only.

Again, there is a much greater association with winter and both outcomes. In the winter season (Nov- Feb) the prevalence of children dispensed an oral steroid is 1.42 to 1.70 times (42% to 70%) higher than in the non-winter period. Similarly the rate of dispensing (the number of oral steroids dispensed /numbers eligible) is 1.42 to 1.75 times (42% to 75%) higher in the winter period.

For every one unit increase in PM2.5 there is an increase in the order of 1.06 to 1.08 (6% to 7%) in the prevalence of children (0-4 years) dispensed an oral steroid, and in the rate of dispensing of oral steroids to children (0-4 years) across the region, adjusting for the impact of winter.

Table 9. Age adjusted incidence rate ratio for the prevalence of patients dispensed a short acting bronchodilator

	PM25_Monthly_ Average	NO2_Monthly_ Average	Winter
South Dublin	1.00	1.01	**1.03***
North Cork 1	**1.01***	1.01	**1.09***
North Cork 2	**1.02***	**0.99***	**1.10***
Dublin North	1.00	1.00	**1.05***
Dublin North West	**1.01***	1.00	**1.07***

Table 10. Age adjusted incidence rate ratio for the rate of dispensing of short acting bronchodilator items

	PM25_Monthly_ Average	NO2_Monthly_ Average	Winter
South Dublin	1.00	1.00	**1.03***
North Cork 1	**1.01***	1.01	**1.09***
North Cork 2	**1.02***	**0.99***	**1.10***
Dublin North	1.00	1.00	**1.06***
Dublin North West	**1.01***	1.00	**1.06***

Table 9 estimates the association between the variables of interest (PM2.5, NO2 and winter) with the outcome of interest = prevalence of patients dispensed a short acting bronchodilator , i.e. the number of patients dispensed a short acting bronchodilator /number of GMS eligible patients in that month. Table10 estimates the association between the variables of interest with the outcome of interest = rate of dispensing of short acting bronchodilator items, i.e. the number of short acting bronchodilator items dispensed/ number of GMS eligible patients in that month.

Again, winter has the strongest association with outcome, in that both the prevalence of patients dispensed a short acting bronchodilator, and the rate of dispensing of short acting bronchodilator items increases by 3-10% in the winter compared with the non-winter period. For every one unit increase in PM2.5, the prevalence of patients dispensed a short acting bronchodilator increases by a factor of 1.01 to 1.02 (1%-2%) depending on which region, adjusting for the impact of winter. Similar increases are observed in the rate of dispensing of short acting bronchodilator items.

There is no association observed between PM2.5 and either outcome in South Dublin or Dublin North. There is no association between NO2 and either outcome, and when one uses the Portlaoise value of NO2 as a proxy for North Cork (North Cork 2) a negative association is observed.

Table 11. Incidence rate ratio for the prevalence of children (0-4 years) dispensed a short acting bronchodilator

	PM25_Monthly_ Average	NO2_Monthly_ Average	Winter
South Dublin	1.03	1.02	1.24
North Cork 1	1.03	1.01	**1.52***
North Cork 2	**1.04***	0.99	**1.54***
Dublin North	**1.04***	1.00	**1.34***
Dublin North West	**1.05***	1.00	**1.32***

(Smaller sample size- just uses one information from one age group as opposed to the full analyses which uses data from all age categories, hence even though you see larger IRR with the Pm2.5, not all these reach statistical significance as the confidence intervals of the effect estimate are wider).

Table 12.Incidence rate ratio for the rate of dispensing of short acting bronchodilator items to children aged 0-4 years

	PM25_Monthly_ Average	NO2_Monthly_ Average	Winter
South Dublin	1.03	1.02	1.27
North Cork 1	1.03	1.01	**1.49***
North Cork 2	1.04	0.99	**1.50***
Dublin North	**1.04***	1.00	**1.37***
Dublin North West	**1.05***	1.00	**1.34***

This is the same analysis as Table 9 and Table 10 , this time restricting to children aged 0-4 years only. Again, there is a much greater association with winter and both outcomes. In the winter season (Nov- Feb) the prevalence of children (0-4 years) dispensed a short acting bronchodilator is 1.32 to 1.54 times (32% to 54%) higher than in the non-winter period. Similarly the rate of dispensing is 1.27 to 1.50 times (27% to 50% higher) in the winter period.

For every one unit increase in PM2.5 there is an increase in the order of 1.04 to 1.05 (4% to 5%) in the prevalence of children (0-4 years) dispensed a short acting bronchodilator, and in the rate of dispensing of short acting bronchodilator items , adjusting for the impact of winter in Dublin North and in Dublin North West.

There were mixed result for North Cork and no statistically association between PM2.5 and either outcome in South Dublin.

Appendix 1. **Respiratory medications** used in the analysis (oral tablets, Inhalers, nebules and syrups (not injections)

Drug Class	Active Ingredient	Brand names
SABA Short-acting β_2 -adrenoreceptor agonists	salbutamol	Ventolin
		Gerivent
		Steri-neb
		Salomol
		Salbul
		Salamol
		Novolizer
	terbutaline	Bricanyl
	terbutaline (oral)	Bricanyl syrup
	salbutamol (oral)	Ventolin syrup
LABA long-acting beta β_2 -adrenoreceptor agonists	salmeterol	Serevent
	formoterol	Oxis
		Foradil
	indacterol	Onbrez
	oldaterol	Striverdi
SAMA Short-acting muscarinic receptor antagonists	ipratropium	Atrovent
		Ster-ineb
		Ipravent
LAMA Long-acting muscarinic receptor antagonists	tioptropium	Spriva
	aclidinium	Elkira Genuair
	umeclidinium	Incruse Ellipta
	glycopryyronium	Seebri
	triotropium bromide combinations	
SABA_SAMA Combination	salbutamol & ipratropium	Combivent
		Ipramol

Drug Class	Active Ingredient	Brand names
short-acting β_2 -adrenoreceptor agonists & short-acting muscarinic receptor antagonists	fenoterol & ipratropium	Berodual
ICS Inhaler corticosteroid	beclomethasone	Aerobec
		Beclazone
		Becotide
		QVAR
	budesonide	Budesonide
		Pulmicort
		Novolizer
		Budesitan
	fluticasone	Flixotide
	mometasone	Asmanex
	ciclesonide	Alvesco
LABA_ICS Long-acting beta β_2 -adrenoreceptor agonists and inhaled corticosteroid combination	salmeterol & fluticasone formoterol & budesonide	Seretide
		Bufomix
		Duroresp Spiromax
		Symbicort
		Flutiform
		Airflusal Forspiro
	formoterol and beclometasone	Not authorised in Ireland at time of analysis
	formoterol and mometasone	Not authorised in Ireland at time of analysis
	vilanterol &fluticasone	Relvar Ellipta
	formoterol and fluticasone	Not authorised in Ireland at time of analysis

Drug Class	Active Ingredient	Brand names
	salmeterol and budesonide	Not authorised in Ireland at time of analysis
LABA_LAMA Combination ong-acting β_2 -adrenoreceptor agonists & long-acting muscarinic receptor antagonists	indacterol & glycopyrronium	Ultibro
	oldaterol & tiotropium	Spiolto
	vilanterol & umeclidinum	Anoro Ellipta
	formeterol & aclidinium	Brimica Genuair
	formoterol and glycopyrronium bromide	Not authorised in Ireland at time of analysis
Methylxantine	teophylline	Nuelin SA
		Uniphyllin
		Zepholin
	aminophylline	Phyllocontin
Leukotriene receptor antagonist	zafirlukast	Accolate
	montelukast	Singulair
		Montelukast

Note: Oral steroid medications (e.g., prednisolone were not included as a 'respiratory medication). A separate analysis was undertaken examining dispensing of oral steroid medications.

Appendix D

Appendix D: Air Pollution Health Effects Literature Review

D1. Health Conditions

D1.1. Asthma

Asthma is a condition which makes the airways to and from the lungs more sensitive to certain environments / airborne substances or when the person is completing certain actions which increase respiration such as exercising; this sensitivity is further increased in cold, dry air (Mayo Clinic, 2018). Asthma can develop in both children and adults but typically it develops at an early age (Health Service Executive, 2018). The likelihood of having asthma is increased if siblings or parents also have the condition (Asthma Society of Ireland, 2018). When a person with asthma is exposed to the sensitive environment or airborne substances, the muscles in the airways tighten which swells the lining, narrowing the passage of air and then a sticky mucus forms which partially blocks the airways. These symptoms are similar to that experienced in the nasal passages during a cold (Asthma Society of Ireland, 2018). Most asthma sufferers require two types of inhalers to minimise the effects of asthma, a preventer inhaler, which is to be taken on a daily basis to abate the effects of asthma triggers and a reliever inhaler, which is to be taken to reduce the tightening of the muscles (Asthma Society of Ireland, 2018). In extreme cases of asthma, where inhalers are not sufficient to provide sustenance, theophylline tablets or steroids are prescribed to reduce inflammation (Health Service Executive, 2011).

Approximately 235 million people suffer from asthma worldwide (World Health Organization, 2017), around 470 000 of which live in Ireland (Asthma Society of Ireland, 2017). In 2015, the average figures for asthma related deaths in the European Union (EU) countries was 1.1 male and 1.6 female deaths per 100 000 persons and Irish figures are considerably greater at 2.4 male and 2.3 female deaths per 100 000 persons (Eurostat, 2018). It is estimated that Irish state costs relating to asthma are in excess of €500 million every year. The Asthma Society of Ireland Annual Report 2017 (Asthma Society of Ireland, 2017) reported the following average yearly statistics:

- Asthma relates to over 5 000 hospital admissions
- Asthma related cases are reported every 26 minutes in Emergency Departments
- Working adults take 10 days and school children take 12 days sick leave due to asthma

D1.2. COPD

COPD is the term used for a group of diseases which limit the flow of air within the lungs; these include chronic bronchitis, emphysema and chronic obstructive airways disease (Health Service Executive, 2011; World Health Organisation, 2019). Emphysema is a disease which targets the alveoli, the small chambers at the ends of the airway branches within the lungs, where the gas exchange of carbon dioxide and oxygen occurs, as shown in Figure D.1. The disease causes the walls of the alveoli to rupture, resulting in reduced area for gas exchange to occur (Mayo Clinic, 2019). Chronic bronchitis targets the bronchial tubes, which are the airways that direct oxygen to the alveoli as shown in Figure D.1. As a result, the walls of the tubes swell and the lungs create more mucus, which block the airways leading to breathing difficulties (Mayo Clinic, 2019). COPD is more common in people aged over 35 years and people with asthma are also more vulnerable to developing COPD (Health Service Executive, 2011). Smoking is considered to be the main cause of COPD but numerous other factors have been proven to increase the chances of developing the disease and these include indoor and outdoor air pollution and exposure to fumes or dust in the workplace (World Health Organisation, 2017; Health Service Executive, 2011). COPD can also be hereditary and can develop through a genetic condition known as alpha-1 antitrypsin (AAT) deficiency but is less common than the aforementioned factors (Johnson, 2018). Similar medications to those prescribed for asthma are used to mitigate flare-ups of COPD. In severe cases, more extensive treatment methods could be used such as oxygen therapy, non-invasive ventilation or lung volume reduction surgery or transplant but positive results for these type of surgeries are limited (Health Service Executive, 2011; Mayo Clinic, 2019).

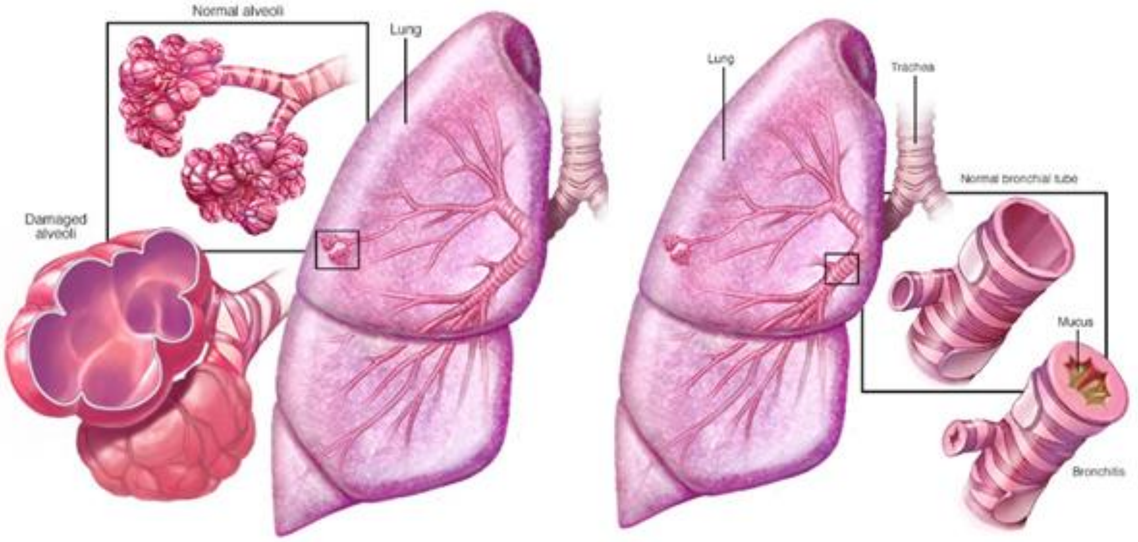

Figure D.1: COPD Diseases - Emphysema (Left) and Chronic Bronchitis (Right) (Mayo Clinic, 2019)

It is estimated that 64 million people are affected by COPD worldwide and that approximately 200 000 are resident in Ireland (World Health Organisation, 2019; Health Service Executive, 2011). Only 110 000 people have been diagnosed with COPD as a large proportion of those affected, who are smokers, tend to disregard the issue due to it being a smoking related cough, which is the dangerous issue as if it is left untreated it can lead to death (Health Service Executive, 2018; World Health Organisation, 2019). In 2015, the World Health Organisation estimated that 5% of all deaths (3.17 million) were attributed to COPD with most occurring in lower income countries. Similar to the asthma statistics, death rates relating to chronic lower respiratory diseases in Ireland were above the average for EU countries of 53.7 male deaths and 25.7 female deaths per 100 000 persons, with 71.4 and 50.1 male and female deaths per 100 000 persons respectively (Eurostat, 2018).

D1.3. Angina

Angina is a symptom of ischaemic heart diseases, which are diseases that cause a reduction of blood flow to the heart, creating pain or tightness in the chest and is commonly linked to a disease known as atherosclerosis (Health Service Executive, 2011; Mayo Clinic, 2019; Irish Heart Foundation, 2019). Atherosclerosis is the build-up of plaque which attaches to the inside of the artery walls and begins to harden over time, narrowing the passage within arteries and reducing blood flow, as shown in Figure D.2 (National Heart, Lung, and Blood Institute, 2019). Beta-blockers are commonly prescribed to reduce heart rate, therefore, reducing the amount of oxygen and blood required and also reducing the chances of a heart attack. Nitrates are another form of medication prescribed to reduce angina; these are taken in advance of activities which are known to exacerbate the issue to relax the blood vessels and widening the pathway through the vessel. Antiplatelet medication such as aspirin can also be prescribed to reduce the chances of developing blood clots in the section of the artery which is partially blocked by plaque by making the blood less viscous (Health Service Executive, 2011; Mayo Clinic, 2019).

Angina is more common in the older population, with approximately 14% of people in Ireland, aged 65 years and over, have had a heart attack or angina (Health Service Executive, 2011). Death rates for ischaemic heart diseases in Ireland are above the EU average of 171.7 male deaths and 94.8 female deaths per 100 000 people, at 203.5 and 107.2 male and female deaths per 100 000 people respectively (Eurostat, 2018). Female deaths from other ischaemic heart diseases, excluding myocardial infarction, were the only category below the EU average (Eurostat, 2018). People who smoke or have diabetes, high blood pressure, poor diets, very little exercise, or heart disease are more vulnerable to experiencing angina and risk can also be increased if there is a family history of angina (Health Service Executive, 2011).

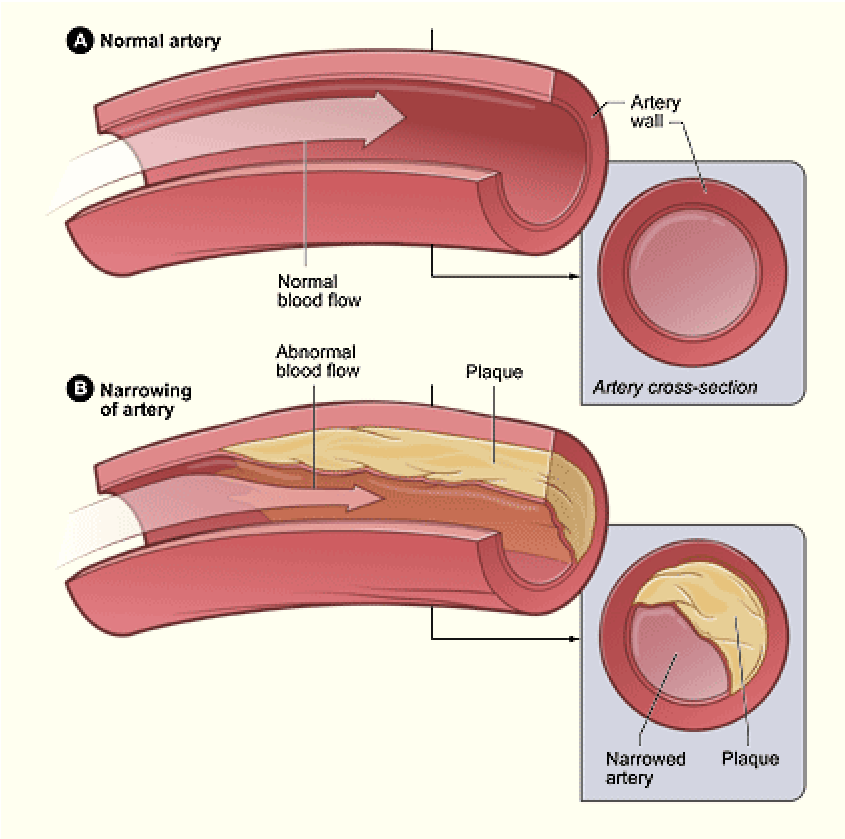

Figure D.2: Atherosclerosis in the Arteries (National Heart, Lung, and Blood Institute, 2019)

D1.4. Myocardial Infarction

Myocardial infarction is more commonly known as a heart attack and the most common cause of this condition is coronary heart disease, whereby arteries become clogged by plaque (Mayo Clinic, 2020). Coronary heart disease risk is increased by smoking, high cholesterol, high blood pressure, diabetes or being overweight (National Health Service, 2019). A number of less common causes also lead to heart attacks such as drug misuse or a lack of oxygen in the blood (Health Service Executive, 2021). Angina (described in Section D1.3) is one of many symptoms of heart attacks including pain spreading to other parts of the body (arms, jaw, neck, back and tummy), feeling lightheaded or dizziness, shortness of breath or feeling nauseated (National Health Service, 2019). The most common cause of deaths in Ireland is heart disease and approximately 6 000 cases of heart attacks are experienced every year in Ireland (CROÍ, 2022). Basic lifestyle changes or minimising exposure to common risk factors can reduce the number of heart disease cases by up to 80% (CROÍ, 2022).

D2. Epidemiological Studies

D2.1. Confounding Factors

A number of studies based on single pollutant models of NO_2 have identified connections to respiratory (McCreanor et al., 2007; Moshammer et al., 2006; von Klot et al., 2002; Strak et al., 2012; Bruske et al., 2010; Tolbert et al., 2007; Jalaludin et al., 2007) and cardiovascular (Szyszkowicz, 2009; Ponka & Virtanen, 1996; Wellenius et al., 2012; Llorca et al., 2005; Szyszkowicz, 2007) health effects but these types of models do not account for potential confounding from other pollutants and the results only indicate health effects from a pollutant mixture with increasing NO_2. The ambient concentrations of several other air pollutants are highly correlated with ambient NO_2 concentrations, including carbon monoxide (CO), ozone (O_3), $PM_{2.5}$, PM_{10} and EC. In particular, studies to date in areas with close proximity to heavily trafficked roads have had difficulty excluding the effects of these pollutants and other confounding factors when examining the independent health effects of NO_2 (United States Environmental Protection Agency, 2016).

Studies on health effects independently caused by $PM_{2.5}$ are more advanced than those addressing NO_2, with the United States Environmental Protection Agency declaring that there is sufficient evidence to link both short-term and long-term $PM_{2.5}$ exposure to mortality and cardiovascular effects (United States Environmental Protection Agency, 2009), as shown in Table D.1 below. Further analysis, which accounts for confounding factors, is required to link exposure to respiratory health effects. There is limited evidence available to support links between PM_{10} and Ultrafine Particles (UFPs) (particulate matter less than 0.1μm in diameter) exposure and health effects. Reported short-term exposure correlation coefficients between $PM_{2.5}$ and NO_2 have been highly inconsistent with values ranging from 0.2 to 0.82 (Mar et al., 2000; Burnett et al., 2000; Moshammer et al., 2006; Ko et al., 2007; Tolbert et al., 2007; Jalaludin et al., 2007; Andersen et al., 2008; O'Connor et al., 2008; Suh & Zanobetti, 2010; Darrow et al., 2011; Baxter et al., 2013; Schembari et al., 2013). Similarly, correlation coefficient results from season to season have been inconsistent, with a number of short-term exposure studies showing limited change in correlation between summer / warm period and winter / cold period measures (Strickland et al., 2010; Levy et al., 2014) and other studies showing large variations, some with higher correlation in winter and others indicating stronger correlation in summer (Sarnat et al., 2001; Sarnat et al., 2005; Dimitriou & Kassomenos, 2014). Long-term $PM_{2.5}$ correlation results show similar inconsistencies with coefficients varying between 0.02 and 0.9 (Eeftens et al., 2012; Gan et al., 2012).

Table D.1: $PM_{2.5}$, $PM_{10-2.5}$ and UFPs Exposure Health Effects (United States Environmental Protection Agency, 2009)

Short-Term $PM_{2.5}$ Exposure	
Health Effects	***Determination***
Cardiovascular	Causal Relationship
Respiratory	Likely Causal Relationship
Mortality	Causal Relationship
Central Nervous System	Inadequate to Infer Causal Relationship

Long-Term $PM_{2.5}$ Exposure	
Health Effects	***Determination***
Cardiovascular	Causal Relationship
Respiratory	Likely Causal Relationship
Mortality	Causal Relationship
Reproductive and Developmental	Suggestive of Causal Relationship
Cancer, Mutagenicity and Genotoxicity	Suggestive of Causal Relationship

Short-Term $PM_{10-2.5}$ Exposure	
Health Effects	***Determination***
Cardiovascular	Suggestive of Causal Relationship
Respiratory	Suggestive of Causal Relationship
Mortality	Suggestive of Causal Relationship
Central Nervous System	Inadequate to Infer Causal Relationship

Long-Term $PM_{10-2.5}$ Exposure	
Health Effects	***Determination***
All Health Effects *(Cardiovascular, Respiratory, Mortality, Reproductive and Developmental, Cancer, Mutagenicity and Genotoxicity)*	Inadequate to Infer Causal Relationship

Short-Term UFPs Exposure	
Health Effects	***Determination***
Cardiovascular	Suggestive of Causal Relationship
Respiratory	Suggestive of Causal Relationship
All Other Health Effects *(Mortality and Central Nervous System)*	Inadequate to Infer Causal Relationship

Long-Term UFPs Exposure	
Health Effects	***Determination***
All Health Effects *(Cardiovascular, Respiratory, Mortality, Reproductive and Developmental, Cancer, Mutagenicity and Genotoxicity)*	Inadequate to Infer Causal Relationship

The United States Environmental Protection Agency published an ISA with determinations on the likelihood of health effects which are independent to CO exposure, using the ranking described in Section 2.5 (United States Environmental Protection Agency, 2010). As shown in Table D.2 below, the only health effect which has sufficient evidence linking CO as likely causal, is cardiovascular morbidity due to short-term exposure to the pollutant, but further studies are required to reduce effects linked to confounding factors such as other pollutants. A number of short-term exposure studies have found that CO has a considerably high correlation with NO_2, with correlation coefficients in the range of 0.6 to 0.92 (Mar et al., 2000; Burnett et al., 2000; Kim et al., 2006; Schildcrout et al., 2006; Villeneuve et al., 2007; Jalaludin et al., 2007; Tolbert et al., 2007; Andersen et al., 2007; Steinvil et al., 2008; Delfino et al., 2009; Darrow et al., 2011; Tao et al., 2012; Laurent et al., 2013). Results from summer or warm period studies show consistently high correlations with CO but results in winter or cold periods are inconsistent, with reported correlation coefficients varying from 0.16 to 0.79 (Sarnat et al., 2001; Strickland et al., 2010; Polidori & Fine, 2012; Wichmann et al., 2012; Levy et al., 2014). Polidori & Fine (2012) found that high correlations between CO and NO_2 continue to exist with increasing distance from roads. This indicates that CO, which is also known to be heavily linked to traffic, has a similar spatial distribution as NO_2. Darrow et al. (2011) illustrated that correlations with NO_2 are reasonably consistent throughout the day, further reinforcing that CO is predominantly a traffic pollutant.

Table D.2: Carbon Monoxide Exposure Health Effects (United States Environmental Protection Agency, 2010)

Long-Term and Short-Term CO Exposure		
Health Effects	***Exposure Period***	***Determination***
Cardiovascular Morbidity	Short-Term	Likely Causal Relationship
	Long-Term	Inadequate to Infer Causal Relationship
Central Nervous System	Short and Long-Term	Suggestive of Causal Relationship
Birth Outcomes and Developmental	Long-Term	Suggestive of Causal Relationship
Respiratory Morbidity	Short-Term	Suggestive of Causal Relationship
	Long-Term	Inadequate to Infer Causal Relationship
Mortality	Short-Term	Suggestive of Causal Relationship
	Long-Term	Not Likely Causal

Correlation coefficients for NO_2 with Elemental Carbon (EC) and Black Carbon (BC) range from 0.58 to 0.69 (McCreanor et al., 2007; Bruske et al., 2010; Strak et al., 2012) and for Ultrafine Particles (UFPs) similar coefficients have been observed, ranging from 0.51 to 0.66 (von Klot et al., 2002; Bruske et al., 2010; McCreanor et al., 2007). This would suggest that the sources of these pollutants are also closely associated with traffic. In addition to other pollutants, there are a large number of other factors such as temperature, humidity, socioeconomic status, race, sex, age, diet, smoking, physical activity and location of residence that are associated with the same health effects as NO_2 exposure (United States Environmental Protection Agency, 2016). A meta-analysis study found links between health effects and NO_2 which were robust to PM adjustment, but there was limited information relating to the primary PM elements such as UFPs and BC, which are difficult to separate from NO_2, to establish that effects were independently linked to NO_2 and not confounded by these elements (Mills et al., 2016).