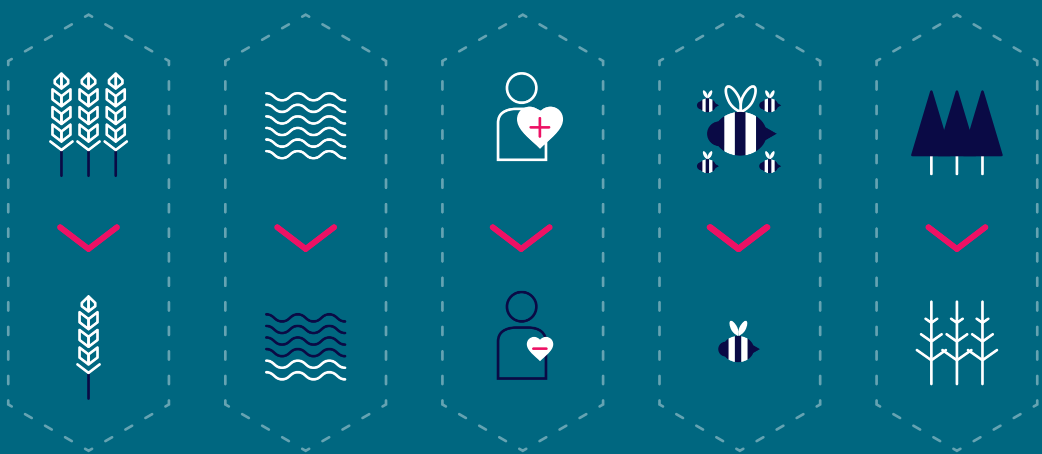
Air Pollutant Marginal Damage Values

Guidebook for Ireland 2015



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Reference
EnvEcon (2015), Marginal Damage Valuations for Air Pollutants in Ireland - 2015, Dublin: EnvEcon Decision Support Series 2015/1

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CONTENTS

INTRODUCTION

This guidebook has been designed to deliver to Irish government Departments, agencies and other analysts, a clear and accessible reference manual with regard to incorporating the value of the marginal damage caused by air pollution in Ireland into their own assessments and evaluations. The marginal damage values in this guidebook are values for the additional costs or benefits associated with an incremental (marginal) change in emissions and associated concentrations of a given air pollutant in Ireland. It is intended that the guidebook can be used in a variety of contexts and in tools such as regulatory impact assessments, cost-benefit analyses and multi-criteria analyses.

This guidebook is intended to aid decision making in this regard and to complement the Department of Public Expenditure and Reform and the Central Expenditure Evaluation Unit's guidelines **(www.publicspendingcode.per.gov.ie)** on economic appraisal and cost-benefit analysis, and the associated guidance notes on incorporating CO_2 into capital appraisal.

The estimates in this guidebook are an advance on prior nationwide air pollutant valuation estimations for Ireland which, in deriving their figures, have generally parsed international estimates of aggregate damage values for Ireland. The estimates are based on data at a country and county level using up-to-date national data and international research, as well as leading-edge in-house analytical methodologies developed by **EnvEcon.** The valuation estimates include both human health impacts (e.g. premature deaths and morbidity) and environmental damage (e.g. damage to crops, acidification and eutrophication) for each of the defined pollutants. The values developed and presented in this guidebook are designed principally for use in assessments and evaluations for Ireland, many of which heretofore have neglected to, or been unable to, consider air pollution impacts.

As international and national circumstances change, there is a case for updating the values in this guidebook based on revised emission outcomes, enhanced measurement data and potential advancements in associated science and research. In particular, improved and extended monitoring data for pollutant concentrations is a critical area for the future. It should be further noted, however, that in the context of major air pollution impact assessment, more refined case- and locality-specific methods are possible and are recommended. In situations where major investments or policy interventions are planned, or indeed where there is a high probability of substantial impacts, case-specific studies are recommended. Please contact **EnvEcon** for further information on tailored assessments.

CONTEXT: WHAT ARE AIR POLLUTANTS AND WHY DO THEY MATTER?

Air pollutants are certain gases and small particles that circulate in the atmosphere. Air pollution can be generated by natural sources (e.g. volcanic eruptions) or anthropogenic sources (e.g. combustion engine car use). Once released into the atmosphere, air pollution is capable of travelling to locations other than its point of origin, and this gives rise to the issue of 'transboundary' air pollution. In other words, damage from air pollutants may occur in places quite far away from the point where the pollutants were initially released.

A further complexity with respect to assessing the impacts of air pollutants is the cumulative impact of air pollution in terms of effects. Air pollution from multiple sources can combine and interact in a given location to give rise to higher pollutant concentration levels that can in turn have more severe impacts. For example, in simplified terms, a given ecosystem may be somewhat more resistant to damage from lower concentrations of air pollutants, and may not experience significant major damage from a nearby air pollution source. However, where the nearby air pollution combines with additional air pollution from other sources further afield, the concentrations of air pollutants and the associated damage may be far more pronounced. These transboundary and additive aspects of air pollution have led to considerable international efforts to regulate air pollutant emissions as a means of addressing the health and environmental impacts throughout the wider international community. For this reason, Ireland faces legally-binding European (National Emissions Ceiling Directive 2001/81/EC) and United Nations' (Gothenburg Protocol) ceilings with respect to national emissions of air pollutants, as well as standards for ambient air quality.

Whilst environmental damage (e.g. eutrophication and crop damage) remains an important aspect of air pollution regulation, it is human health considerations that have been the dominant driver of international air pollution regulation in recent years. Levels of fine 'invisible' particulates in the air as well as ground-level ozone concentrations have a direct impact on public health and thereby place a considerable additional cost on society through loss of life, health impairments and the associated societal costs in relation to health care, productivity and well-being. Indeed, there is increasing awareness in the health sector internationally of the potential for air pollution mitigation strategies to deliver societal cost savings and to ease the pressure on national health care services. Recent research by the World Health Organisation (WHO, 2013 a,b) suggests that there are no 'safe levels' of air pollution with respect to human health and goes on to identify the lengthy catalogue of health impacts associated with air pollution exposure in terms of lost working days, reduced activity days and premature death. Furthermore, there is now increased recognition of the relevance of certain air pollutants to the climate change challenge.

Whilst certain aerosols can provide a cooling effect in the atmosphere, other pollutants such as black carbon (BC) or tropospheric ozone (O3) have impacts that cross the 'Air' and 'Climate' policy divide. BC and O3 are classed as 'short-lived climate pollutants' (SLCPs) and carry negative impacts for human health and the environment, as well as contributing to the warming of the atmosphere. The improved understanding of the significance of SLCPs in regard to human health and climate change has served as a catalyst to accelerate international action in this area under the umbrella of bodies such as the Climate and Clean Air Coalition.

Air pollutants are, therefore, extremely important to consider within impact assessments relating to capital projects and policy decisions. This guidebook aims to facilitate the necessary recognition of air pollutants in such assessments by offering accessible national estimates of marginal damage values per tonne of emissions.

AIR POLLUTION IN IRELAND

MAJOR AIR POLLUTANTS

- NH_3 — Ammonia
- NO_x — Oxides of Nitrogen
- PM — Particulates
- O_3 — Ozone
- VOC — Volatile Organics
- SO_2 — Sulphur Dioxide
- CH_4 — Methane
- PAHs — Polycyclic aromatic hydrocarbon
- N_2O — Nitrous Oxide
- HFCs — Hydrofluorcarbons

SOURCES OF AIR POLLUTANTS

Agriculture | Commercial | Industry | Natural | Transport | Residential | Power | Waste

TRANSFORMATION AND MOVEMENT OF POLLUTANTS

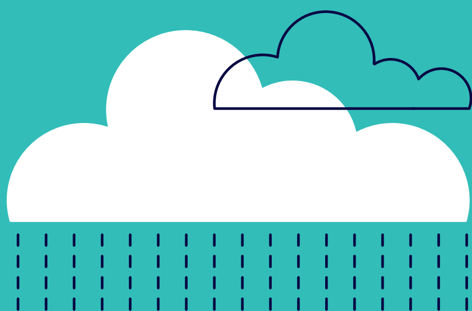
Air Pollutants can interact and form different air pollutants

Sunshine + Nitrogen Oxides + Volatile Organics = Ozone

Sunshine + NO_x + VOC = O_3

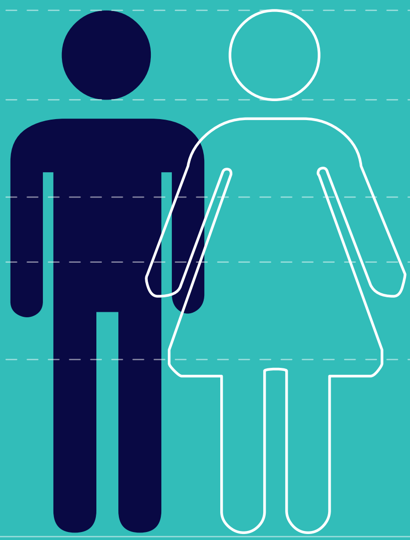
$2NH_3 + SO_2$ = Secondary PM

(NH_3 NH_3) + SO_2 = PM



Air Pollution affects local areas but also travels with wind and rain to have an impact on a local, regional and global scale.

HEALTH IMPACTS



Accepted Health Impacts List

- Headaches, Anxiety (SO_2)
- Central Nervous System Impact and Stroke (PM)
- ENT Irritation and breathing Difficulties (O_3, PM, NO_2, SO_2, PAHs)

- Cardiovascular Disease (O_3, PM, SO_2)
- Asthma and Reduced Lung Function (PM, O_3)
- Lung Cancer (PAH)

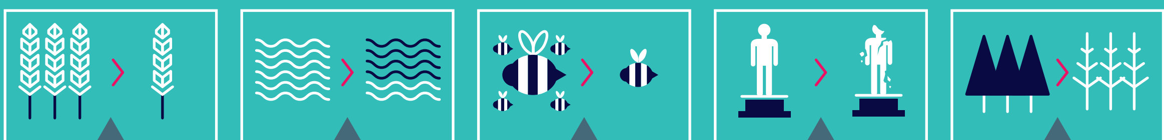
- Impacts on Liver, spleen and blood (NO_2)

- Impacts on Reproductive System (PM)
- Low Birth Weight, Premature Birth (PM)

Ongoing Research Continues on Air Pollution Links to:

- Learning Disabilities
- Alzheimer's
- Depression
- Autism
- Obesity
- Birth Defects
- Diabetes

ENVIRONMENTAL IMPACTS



Crop Yields | Water Systems | Species diversity | Buildings & Materials | Forests

SUMMARY COSTS/IMPACTS

*"WHO (2015) and EnvEcon (2015) research estimate over **700 premature deaths per annum** attributable to ambient air pollution in Ireland, with total health costs (mortality and morbidity) in excess of **€2bn per annum.**"*

IMPROVING AIR QUALITY

There are many ways to improve air quality with incremental changes in technologies and behaviour such as:

Unfiltered › Filtered | Cars › Bus | Diesel › Cycling | Diesel › Electric

Uninsulated › Insulated | Open Fire › Gas Boiler | Oil › Electric | Splash Plate › Trailing Shoe

Monitoring
The EPA play a major role in monitoring national Air Quality and in maintaining a national Inventory of Air Pollutants

Modelling
EnvEcon operate GAINS Ireland to offer Integrated Climate and Air impact analysis and policy development

Management
Government play a key role in determining and implementing policies and measures to meet European and United Nations targets

CONTEXT: WHICH AIR POLLUTANTS ARE CONSIDERED IN THIS GUIDEBOOK?

As part of this research **EnvEcon** have analysed the impacts associated with fine particulates, ozone and acid precursors by considering the following five primary air pollutants:

- **NO_x** Nitrogen Oxides
- **SO_2** Sulphur Dioxide
- **NH_3** Ammonia
- **NMVOC** Non-Methane Volatile Organics
- **$PM_{2.5}$** Particulate Matter (2.5 microns)

In this research we do not, as of yet, include the following organic pollutants and heavy metals for valuation; Benzene, Polycyclic Aromatic Hydrocarbons (PAHs), Dioxins and Furans, Mercury, Lead, Nickel, Chromium, Cadmium and Arsenic.

Neither do we include, at this point in time, some of the other SLCPs, specifically; Methane (CH_4), Hydrofluorocarbons (HFCs)

It is noted that these pollutants, that are not included for valuation analysis at this point, are also associated with combustion activities and other sources, and can also impact negatively on human health and the environment. Where these pollutants are ultimately included in the assessment they would be expected to add to the net health and environmental impacts associated with air pollution in Ireland. There are however complexities and potential overlaps in damage estimation as increasing numbers of specific pollutants are included. Nonetheless, ceteris paribus, we expect that the marginal damage value estimations provided in this guidebook as a consequence of specific air pollutants are more conservative than would be the case if a broader selection of air pollutants were considered.

"MARGINAL DAMAGE VALUE ESTIMATIONS IN THIS GUIDEBOOK ARE MORE CONSERVATIVE THAN WOULD BE THE CASE IF A BROADER SELECTION OF AIR POLLUTANTS WERE CONSIDERED."

CONTEXT: WHAT ARE MARGINAL DAMAGE VALUES AND HOW ARE THEY ESTIMATED?

The marginal damage values are the value for the additional costs or benefits associated with an incremental (marginal) change in the emissions and associated concentrations of a given air pollutant in Ireland. They do not measure the total costs associated with those air pollutants, i.e. total damage. Therefore, it is important to note that one cannot infer from a low marginal damage value for a pollutant, that the total damage imposed by the concentration of that pollutant is also low.

Estimating and valuing the damage associated with a quantity of an air pollutant emitted is an extremely challenging task. As distinct from using a valuation method which places a 'price' on CO_2 emissions using a market value, air pollution marginal cost estimation requires consideration of national and international emissions, the interactions between pollutants, their dispersion and concentration, the sensitivity and exposure of people and the environment, and the valuation of the damage caused by the ultimate exposure.

The values presented in this guidebook have been developed de novo for Ireland, drawing on a variety of national data and international scientific evidence. It is however important to recognise that this is a first version of this work and some future improvements are expected and planned in the coming years. Specifically, there are some major international research projects underway regarding the estimation of health and ecosystem damage and the associated valuation of that damage (e.g. ecosystem services). Updates to this scientific literature will be important.

Furthermore, EnvEcon recognises that more detailed dispersion modelling and improved empirical monitoring of emission concentrations in Ireland will enable more accurate measurement of values in the future. Overall, however, given current methodologies, data and knowledge available, the estimates presented in this guidebook represent reasonable estimations for use in current economic evaluations and are an advance from previous estimates.

The Methodology used considers the following five areas which are explained in more detail below:

1. An estimated baseline level of spatially-allocated air pollutant emissions and concentrations across Ireland.
2. The presence and sensitivity of receptors (e.g. environment/people) affected by air pollution.
3. The damage associated with air pollution exposure and the corresponding valuation of that damage.
4. The association between emission changes and pollutant concentrations across Ireland.
5. The marginal change in damage and damage values associated with changes in pollution concentrations.

METHOD: SPATIAL DISTRIBUTION OF EMISSIONS

Pollution sources were initially divided into either point sources (e.g. power stations, industrial incinerators) or area sources (e.g. residential, transport or agricultural). Emissions from the point sources were spatially allocated using an improved inverse distance model that considered Irish meteorological data and other parameters.

Emissions from the area sources were allocated evenly along the relevant areas for that source, such as along a road or rail network. Prior work by the EPA in regards to spatial distribution of air pollutant emissions was also considered, in particular with regard to the location of agricultural livestock and associated emissions. Residential sector emissions were allocated utilising census data and other work. These area and point sources of pollution were then summed to generate an aggregate spatially allocated level of emissions in a given area. This work utilised, and is consistent with, the 2014 version of the 2010 EPA emission inventory.

METHOD: FROM EMISSIONS TO CONCENTRATION

To move from spatially allocated levels of emissions to concentrations of pollution, EnvEcon has conducted extensive 'spatial' regression work to reconcile refined estimates of nationally distributed emissions with empirical estimates of pollutant concentrations from the national air quality monitoring network. This approach takes estimates of where pollution is occurring, and then marries this with observed data which implicitly captures key factors such as weather patterns, dispersion, background concentrations and natural sources.

The relationships estimated for the spatial emissions and the monitored readings over time were then used to estimate concentrations in areas where comparable monitoring stations are not available. This empirical approach is believed to offer a robust and novel method to estimate concentrations, but is dependent on the quantity and quality of monitoring.

METHOD: RECEPTORS AND RELEVANT PARAMETERS

Receptors in this context can be loosely described as those things affected by the air pollutants. There are two principal categories of receptors utilised in this work. These are people, for estimating human health impacts, and natural areas for ecosystem and environmental impacts. The population distribution used is drawn from the 2011 Census records. These data are paired with average income estimations derived from analysis of the Pobal HP Deprivation Index (www.pobal.ie). Mortality, Morbidity and hospital expenditure data are sourced from the Central Statistics Office (CSO), various national health statistics and reports, and the mortality indicator database of the World Health Organisation (WHO). All of these values assisted in the valuation of health damage.

Spatial land cover data, including arable lands (crops), pastures, natural areas (e.g. coniferous forests, deciduous forests, mixed forests, natural grasslands, sparsely vegetated areas, inland marshes and peat bogs) are derived from the URBIS database at University College Dublin (UCD). These data have also been supplemented or checked against records from other sources (e.g. Department of Agriculture, Forestry and the Marine). Market resource prices were used to support damage valuation estimation to specific categories.

"THE EMPIRICAL APPROACH TAKEN IS BELIEVED TO OFFER A ROBUST AND NOVEL METHOD TO ESTIMATE CONCENTRATIONS, BUT IS DEPENDENT ON THE QUANTITY AND QUALITY OF MONITORING."

METHOD: ESTIMATING HEALTH IMPACTS

Based on concentration-response functions, we assess the health impacts (mortality and morbidity) associated with $PM_{2.5}$ and ground level ozone. Ozone is formed at ground level by a reaction of other pollutants, specifically VOC, NO_x and CO, in the presence of sunlight. Such ground level ozone is a strong oxidising agent and can cause damage to human health and vegetation. To consider changes in the levels of ground level ozone formation, the marginal increase in those precursors of ozone are used. Whilst VOC and NO_x both serve as ozone precursors, all of the health and environment related ozone damage has been allocated to VOCs.

The reason for this decision is that our empirical studies suggest that Ireland is generally in a "VOC limited" condition – a state where increasing VOC will be expected to increase ozone, whilst increasing NO_x is expected to actually reduce ozone[1]. Therefore, NO_x is not considered a strong precursor of ozone under these specific Irish circumstances.

For direct health damage caused by primary $PM_{2.5}$, ozone and NO_x, the methods and parameters used draw upon the Institute of Occupational Medicine model based on life-tables that have been adjusted by EnvEcon with Irish parameters and using Irish input. Further information for the theoretical base and relevant parameters have been drawn from the major WHO EU work in 2013 and Holland (2014). The research has also considered the latest methods and tools for assessing health risks of air pollution and estimating Values of Statistical Life (VSL) (WHO EU, 2014). As for health damage caused by the precursors of secondary particulate matter, NO_x, NH_3, SO_2 and VOC, a primary "PM-equivalent" exchange rate and corresponding approaches from Amann and Wagner (2014), are used.

1 Discussion relating to the VOC limited condition can also be found in reference to "the weekend effect" in the literature. In Ireland, the EPA Air Quality in Ireland 2013 report also suggests that ground-level ozone is depleted through reactions with traffic-emitted pollutants. As a consequence of this, the levels of ozone can be found to be higher in rural areas than in urban areas. As NO_x is a major pollutant from transport emissions, the increase of NO_x emissions, which is mixed with those pollutants that deplete ozone, may be the cause of the observed reduction of ozone concentrations in urban and road network proximate areas. As a result of these observations we have determined that VOC is a better indicator than NO_x in relation to the formation of ground-level ozone and use it as the sole precursor.

METHOD: ESTIMATING ENVIRONMENTAL IMPACTS

The environmental damage from these air pollutants can be split between ozone related damage on the one hand, and acidification and eutrophication damage by NO_x, NH_3 and SO_2 on the other. With respect to the latter, the models used and some key parameters, were derived from the international literature and some of the major EU research project outputs in this area such as "Assessment of Biodiversity Losses" (NEEDS, 2006).

As noted, we recognise that the future release of other environmental damage estimation research (e.g. the ECLAIRE project) may be important to review into the future. For ozone damage the models and parameters were derived from a number of literature sources and adapted as appropriate (e.g. Mills et al., 2007 and CLRTAP, 2014).

"THE RESEARCH HAS CONSIDERED THE LATEST METHODS AND TOOLS FOR ASSESSING THE HEALTH RISKS OF AIR POLLUTION."

APPLICATION: HOW SHOULD THESE BE USED?

The specific approach to the use of the values is to be determined by the individual analyst. However, the intention is to deliver a set of values that can be used in a simple damage cost approach. The concept being that the values may be incorporated into cost-benefit style analysis to offer a weighting in the function for the associated costs or benefits associated with a given change in the tonne emission levels of any or all of the defined air pollutants.

A simple sample case of how the guidebook can be used to support appropriate weighting and valuation of air pollution in the decision making process is outlined in Box 1. EnvEcon can also provide, by request, a case specific and fully tailored impact pathway cost-benefit analysis or regulatory impact assessment.

BOX 1: SAMPLE CASE FOR THE USE OF THE MARGINAL DAMAGE VALUES IN THIS GUIDEBOOK

How to use the marginal damage values (sample case)

An analyst is assessing a proposed infrastructure project which involves reactivating an old industrial facility and making changes to the nearby road network. It is anticipated that this project will result in increased industrial emissions as well as higher levels of traffic associated with the facility. The analyst proceeds as follows:

1. The analyst first reviews the scale of the proposed project and the magnitude of the expected outcomes for all relevant criteria. This scoping process will inform whether a more detailed analysis may be necessary. Let us assume that the analyst identifies a number of impacts in regard to air pollution where the approach in the guidebook is appropriate.

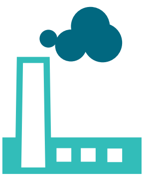
2. For the environmental costs related to air pollutants, the analyst must estimate the annual increase in tonne emissions of air pollutants associated with the proposal. These emissions may vary over the years, and the incidence of the pollutants may be spread over different areas (e.g. urban, rural or national). The estimation of the change in emissions, their dispersion and incidence is left to the analyst.

3. In this sample case the analyst estimates that the project will result annually in 25 tonnes of additional NO_x and 5 tonnes of primary $PM_{2.5}$ emitted in a medium sized urban area, with 75 tonnes of NO_x and 10 tonnes of primary $PM_{2.5}$ for nearby rural areas. The analyst should use the appropriate urban and rural values for Ireland.

4. Using these values, the annual marginal damage value associated with the emission increases as a result of this project would be (25 x €1,550 – NOx urban medium) + (5 x €22,825 $PM_{2.5}$ urban medium) + (75 x €925 NOx rural) + (10 x €6,600 $PM_{2.5}$ rural medium) = €288,250 per annum. The analyst may apply a discounting or compounding rate to the values according to their chosen methodology. These marginal damage values may then be used in the overall evaluation as appropriate.

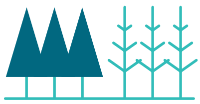
APPLICATION: WHY SHOULD THESE BE USED IN IRELAND?

Recent research by the WHO (2014) indicates that air pollution is the world's largest single environmental health risk. A comprehensive research study in 2012 indicated that approximately 7 million people died in that year as a result of air pollution exposure. Provisional analysis by EnvEcon indicates that annual premature deaths as a result of outdoor air pollution exposure is a multiple of the number of road deaths (a level of roughly 200 per annum in recent years[2]) in Ireland. This is before assigning any weighting to the effects on morbidity, productivity and quality of life, or indeed to international health impacts from Irish emissions. From a human health perspective, therefore, air pollution should be considered a significant matter for public policy in Ireland.



"FROM A HUMAN HEALTH PERSPECTIVE, THEREFORE, AIR POLLUTION SHOULD BE CONSIDERED A SIGNIFICANT MATTER FOR PUBLIC POLICY IN IRELAND."

Furthermore, as noted, air pollution also has direct negative impacts on the natural environment and ecosystem services both within Ireland and across borders, with certain SLCPs highly relevant in the context of climate policy. In addition to these direct negative impacts, there are also a number of international regulations to which Ireland is a party, whereby Ireland is legally obliged to limit and reduce national emissions of these pollutants or face significant persistent fines for non-compliance (Kelly, J.A, 2014)[3]. These factors offer a compelling justification for recognising air pollution outcomes as part of policy appraisals and investment decisions.



"FURTHERMORE, AS NOTED, AIR POLLUTION ALSO HAS DIRECT NEGATIVE IMPACTS ON THE NATURAL ENVIRONMENT AND ECOSYSTEM SERVICES BOTH WITHIN IRELAND AND ACROSS BORDERS."

2 Road Safety Authority statistics for 2009 to 2013 (2013 provisional) indicate an average of 198 deaths per annum on Irish roads.

3 Under a given Europe Directive (e.g. National Emission Ceilings Directive 2001/81/EC) a failure to comply with emission ceiling targets could plausibly result in initial annual fines of between €3million and €13million euro, which would persist until compliance is achieved.

RESULTS: MARGINAL DAMAGE VALUES FOR AIR POLLUTANTS

Marginal damage values for Ireland per tonne per annum are shown in Table 1. All values have been rounded to the nearest €25 value. National, urban and rural values are presented. The values include damage in Ireland for:

- Direct health damage (mortality and morbidity) caused by particulates, NO_x and ozone.
- Biomass loss caused by ozone (crops, coniferous forests, deciduous forests and semi-natural lands).
- Eutrophication and acidification of natural areas by NO_x, NH_3 and SO_2.
- Secondary PM health impacts for NO_x, NH_3, SO_2 and VOC in the tonne values of each pollutant.

Note also that VOC incorporates all ozone related health and environmental damage. As VOC is a precursor of both ozone and $PM_{2.5}$, the total health damage of VOC provided in the table is the sum of these two channels.

TABLE 1: NATIONAL, URBAN AND RURAL VALUES

Aggregate National Estimate of Marginal Damage Value per Tonne of Pollutant (€2010 per tonne per annum)					
	NO_x	NH_3	SO_2	NMVOC	$PM_{2.5}$
	Incl. Secondary PM	Incl. Secondary PM	Incl. Secondary PM	Incl. Secondary PM & O^3	Primary PM only
Ireland All	€1,000	€825	€4,825	€875	€7,500
Ireland Rural	€925	€650	€4,825	€850	€6,600
Urban Large (Dublin)	€9,350	€13,175	€10,300	€2,675	€67,650
Urban Medium (Pop ≥ 15,000)	€1,550	€3,300	€4,750	€1,550	€22,825
Urban Small (Pop 10,000 - 15,000)	€1,375	€1,500	€5,275	€1,350	€14,800
Small Towns (Pop < 10,000)	€1,150	€1,050	€4,725	€1,025	€9,650

RESULTS: UNDERSTANDING THE VALUES AND VARIATIONS

Sources of variation between values can be explained by differences in underlying factors such as land area and type, population density, age profile of population, base quantity of air pollutants and weather related factors. In general, values for higher population density areas, such as Dublin, will have higher marginal damage values as a major part of the damage valuation is human health damage. In our estimation for Ireland, over 95% of the marginal damage valuation is related to health damage. Understandably in developed and populated areas, damage valuations for natural areas and plants (e.g. biomass loss, eutrophication) are somewhat lower.

For urban areas (especially urban small) and small towns, the values shown in the table are not limited to the built-up areas. The values include damage done to the suburban areas and townlands, as well as their direct neighbouring rural areas. This is to allow for the differing structural patterns between larger cities and smaller urban areas. If this approach was not taken, the similar population density of built-up areas (small or large) in most types of settlements in Ireland would generate similar marginal damage values.

The NH_3 urban large value is notably higher because it is a marginal damage value and NH_3 is limited in such urban areas. The relationship curve between NH_3 emissions and NH_3 concentrations is a concave curve, so in urban areas with near zero NH_3 concentrations, one additional tonne of NH_3 emissions will cause a high positive concentration change in contrast to more rural areas. One may also note that the health impacts of NH_3 are through secondary PM, and PM concentrations are already high in urban areas. Whilst true, this analysis has considered the existing concentration of $PM_{2.5}$ and used this to estimate the marginal damage of $PM_{2.5}$.

The PM equivalent exchange rates have then been applied to the marginal values of $PM_{2.5}$. The concentration change of $PM_{2.5}$ is caused by the concentration change of NH_3 not the quantity of the emissions. NH_3 is very important for the formation of secondary PM (ETC/ACM, 2013) as it reacts with both SO_2 and NO_x in rough ratios of;

- $2NH_3 + SO_2$, and
- $1NH_3 + NO_x$

Its role in the formation of secondary PM results in changes in NH_3 concentrations leading to larger changes in $PM_{2.5}$ concentrations. In addition to the indirect health damage through secondary $PM_{2.5}$ by NO_x, NH_3 and SO_2, acidification effects are included in values of NO_x and SO_2, eutrophication effects are included in NH_3 and NO_x, and direct health impacts are included for NO_x.

"IN OUR ESTIMATION FOR IRELAND, OVER 95% OF THE MARGINAL DAMAGE VALUATION IS RELATED TO HEALTH DAMAGE."

OBSERVATIONS AND FUTURE WORK

We had to take a pragmatic approach to produce a useable guidebook. However, over the course of its development, a number of areas for future work were identified where further research can deliver an increasingly refined and robust set of values for future versions of this guidebook:

1. **Estimating changes in concentrations as related to changes in emissions** is critically important for this work. The EnvEcon approach is innovative and empirical. However, the quantity of monitored emission concentration data was limited. Improvements in regular and reliable monitoring are recommended and can significantly reduce uncertainties surrounding damage-value estimations into the future.
2. **Spatial allocation and distribution of emissions** has been developed at a county and country level as part of this work. This was the most appropriate initial scale for supporting officials working on simple cost benefit analyses nationally, as it enables the recognition of air pollutant damage values in the decision making process. However, EnvEcon can refine the approach to offer much finer scale estimations that would be appropriate for extremely detailed impact pathway assessments nationally.
3. Under this work, it was noted that **ozone concentrations** are reasonably low in Ireland by comparison with other European countries. The thresholds defined for health and environmental damage - SOMO35 (sum of means over 35ppb on daily maximum 8 hour) and AOT40 (Accumulated ozone exposure over a threshold of 40ppb) - are not often breached in the assessments and therefore limited effects are registered. However, where emissions are estimated on a finer scale and with seasonal climatic variation, the incidence and estimation of ozone effects may be enhanced. This can be assessed in future work.
4. A number of major **research projects** are underway that may offer new scientific insight on the complex relationships between air pollution and environmental damage (e.g. biodiversity loss) as well as the ongoing research into the associated health impacts. Furthermore, national data will change and develop over time (e.g. inventory revisions, census 2016). As such, the methodology and data applied by EnvEcon as part of this work can be updated and developed to continue to reflect the best available evidence.
5. Complications arise due to the **complex interactions between pollutants and impacts.** For example, NO_x, SO_2, and NH_3 are all potential sources of secondary particulates, and in some cases are also responsible for direct health impacts in their original forms. The complexities in this regard, for major decisions, warrants the development of a more advanced and dynamic approach to chemical interactions, dispersion modelling and damage cost estimation, which appropriately weights and aggregates the impacts from changes in multiple pollutants simultaneously. EnvEcon are considering the development of a web-based tool that can offer this more complex back-end methodology with an accessible front-end user interface.
6. **Particulates** are a major driver of the damage valuations. However, the toxicity of particulates can vary by source. In a refined version of this work for the future we propose to deliver source-specific marginal damage valuations that account for such variations in toxicity.
7. **Pollutant exposure** will vary on a temporal basis, and there is scope for us to develop refined assessments that allow for variations in concentrations and exposure on a spatial-temporal scale.
8. This study only values the impacts associated with air pollutant concentrations in Ireland. It is possible to extend the analysis to include Irish contributions to **international impacts** as part of the valuation process.

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QUICK ACCESS TABLE FOR MARGINAL DAMAGE VALUES FOR AIR POLLUTANTS IN IRELAND

Aggregate National Estimate of Marginal Damage Value per Tonne of Pollutant (€2010 per tonne per annum)					
	NO_x	NH_3	SO_2	NMVOC	$PM_{2.5}$
	Incl. Secondary PM	Incl. Secondary PM	Incl. Secondary PM	Incl. Secondary PM & O^3	Primary PM only
Ireland All	€1,000	€825	€4,825	€875	€7,500
Ireland Rural	€925	€650	€4,825	€850	€6,600
Urban Large (Dublin)	€9,350	€13,175	€10,300	€2,675	€67,650
Urban Medium (Pop ≥ 15,000)	€1,550	€3,300	€4,750	€1,550	€22,825
Urban Small (Pop 10,000 - 15,000)	€1,375	€1,500	€5,275	€1,350	€14,800
Small Towns (Pop < 10,000)	€1,150	€1,050	€4,725	€1,025	€9,650

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