Department for Environment Food & Rural Affairs

www.gov.uk/defra

Valuing impacts on air quality:

Updates in valuing changes in emissions of Oxides of Nitrogen (NO_X) and concentrations of Nitrogen Dioxide (NO_2)

September 2015

© Crown copyright 2015

You may re-use this information (not including logos) free of charge in any format or medium, under the terms of the Open Government Licence. To view this licence, visit www.nationalarchives.gov.uk/doc/open-government-licence/ or write to the Information Policy Team, The National Archives, Kew, London TW9 4DU, or e-mail: psi@nationalarchives.gsi.gov.uk

This document/publication is also available on our website at

www.gov.uk/air-quality-economic-analysis

Any enquiries regarding this document/publication should be sent to us at

igcb@defra.gsi.gov.uk

PB13912

Contents

1. Introduction

1. The quality of the air impacts upon health and the environment. The impact of public exposure to particulate matter alone has been estimated to reduce average life expectancy in the UK by around six months. This imposes a cost to public health of over £16 billion a year. As a result it is important that impacts on air quality are reflected in decision making.

2. The impact pathway approach (I-PA) is the central recommended approach to value changes in air quality. This approach estimates the consequences of changes in the ambient concentrations of air pollutants for a range of health and environmental outcomes.

3. Recent developments in the evidence now allow the quantification and valuation of the direct effect of exposure to nitrogen dioxide (NO_2) on mortality. Given the significance of this impact and interim recommendations from the Committee on the Medical Effects of Air Pollution this paper updates Defra guidance.

4. This change is only relevant to policies, programmes and projects that impact on NO_2 concentrations. It therefore applies both to actions that directly change NO_2 concentrations and, as far as practicable, to emissions of its precursors. As emissions of oxides of nitrogen (NO_X) are a key cause of NO_2 concentrations the valuations of NO_X emissions have been updated.

5. This guidance is intended to provide a clear understanding on why this change has been made and how it should be applied in practice.

6. The remainder of this document has the following structure:
    - Section 2: Recent developments
    - Section 3: Updates to air quality valuation
    - Section 4: Consequences of this update
    - Section 5: Worked example of damage costs

2. Recent developments

7. Evidence on the health impacts associated with of exposure to NO_2 concentrations has developed significantly over the past few years. Some of the key developments within this area are provided in box 1 below.

Box 1: Recent research publications considering the health impacts of NO_2

1. World Health Organisation (2013). Review of evidence on health aspects of air pollution

In 2013 the World Health Organisation (WHO) released 'Review of evidence on health aspects of air pollution (REVIHAAP)' and Health risks of air pollution in Europe (HRAPIE). These projects made recommendations for concentration–response functions for cost–benefit analysis of particulate matter, ozone and nitrogen dioxide'. The HRAPIE[1] experts recommended applying to adult populations (age 30+ years) a linear Concentration–Response Function for all-cause (natural) mortality, corresponding to a Relative Risk of 1.055 (95% CI = 1.031, 1.08) per 10 µg/m^3 annual average NO_2.

2. Hoek, G., et al. (2013). Long-term air pollution exposure and cardio- respiratory mortality: a review. Environ Health 12(1): 43.

The Hoek et al. review (2013) brings together the evidence from epidemiological studies on the associations between long-term exposure to air pollutants, including 15 studies on NO_x, and mortality. The papers, on which the review is based, were the latest available in January 2013 and covered a wide geographical area. A significant association was identified between NO_X/NO_2 concentrations and all-cause mortality and a pooled estimate per 10 µg/m3 was calculated to be 1.05 (95% CI 1.03, 1.08).

3. Faustini, A., et al. (2014). Nitrogen dioxide and mortality: review and meta-analysis of long-term studies. Eur Respir J 44(3): 744-753.

Faustini et al. (2014) provides pooled estimates of the long-term effects of NO_x/NO_2 and particulate matter on mortality based on published papers from 2004 to 2013 which covered a wide geographical area and included estimates from studies that analysed particles and NO_2. The pooled effect on mortality, based on 12 studies, was 1.04 (95% CI 1.02–1.06) with an increase of 10 µg/m3 in the annual NO_X/NO_2 concentration. The effect on cardiovascular mortality was 1.13 (95% CI 1.09–1.18) for NO_x/NO_2. The NO_x/ NO_2 effect on respiratory mortality was 1.03 (95% CI 1.02–1.03). Four two-pollutant analyses with particulate matter and NO_x/ NO_2 in the same models showed minimal changes in the effect estimates of NO_X/ NO_2, which suggests that, in the few studies using two-pollutant models, the effects of NO_2 and particles (of different sizes) seemed independent.

4. Walton, H., et al. (2015) Understanding the Health Impacts of Air Pollution in London. A report for Transport for London and the Greater London Authority[2].

The report focuses on the mortality impacts that occur within London for particulate matter and NO_2. This study, for the first time, provides an estimate of the mortality burden of NO_2 in London. Walton et al. (2015) used a coefficient chosen on the basis of the WHO HRAPIE recommendations. The report estimates that in London in 2010, the number of deaths attributable to long term exposure to NO_2 is 5,879 deaths. This is in comparison to the estimate that in 2010, the number of deaths attributable to long term exposure to man-made particulate matter ($PM_{2.5}$) of 3,500 deaths. The estimates total cost in London this above health impacts ranged from £1.4 billion to £3.7 billion. Short term exposure to NO_2 was associated with about 420 hospital admissions for respiratory disorders in 2010 in London. The figure for $PM_{2.5}$ is estimated to be 1990 admissions.

---

[1] http://www.euro.who.int/__data/assets/pdf_file/0006/238956/Health-risks-of-air-pollution-in-Europe-HRAPIE-project,-Recommendations-for-concentrationresponse-functions-for-costbenefit-analysis-of-particulate-matter,-ozone-and-nitrogen-dioxide.pdf

[2] https://www.london.gov.uk/sites/default/files/HIAinLondon_KingsReport_14072015_final_0.pdf

8. The Committee on the Medical Effects of Air Pollutants (COMEAP), funded by the Department of Health, provides independent advice to government on the health impacts of air pollution.[3] On 12 March 2015, in light of the new health evidence, COMEAP published a statement entitled "Nitrogen dioxide: health effects of exposure". The committee concluded:

> *From our consideration of authoritative reviews and additional evidence we have reached the following conclusions:*
>
> > *i. Evidence of associations of ambient concentrations of NO_2 with a range of effects on health has strengthened in recent years. These associations have been shown to be robust to adjustment for other pollutants including some particle metrics.*
> >
> > *ii. Although it is possible that, to some extent, NO_2 acts as a marker of the effects of other traffic-related pollutants, the epidemiological and mechanistic evidence now suggests that it would be sensible to regard NO_2 as causing some of the health impact found to be associated with it in epidemiological studies.*
>
> *We have not drawn conclusions on specific health outcomes nor looked in detail at the methodological issues relevant to quantification of effects associated with ambient NO_2 at this stage. We intend to do this and, if appropriate, to consider recommendations for coefficients associating NO_2 with specific health effects, as part of separate work items to be addressed later."*

9. COMEAP have provided an interim steer to Defra on how the latest NO_2 evidence should be reflected in policy analysis. On 24 July 2015 a COMEAP working group on NO_2 wrote to Defra recommending that a coefficient of 1.025 per 10 $\mu g/m^3$ exposure to NO_2 (within the range 1.01 – 1.04)[4] should be used to assess the link between long term exposure to NO_2 and all-cause mortality.[5]

---

[3] https://www.gov.uk/government/groups/committee-on-the-medical-effects-of-air-pollutants-comeap

[4] A 1.025 coefficient means that if population exposure to NO_2 were to increase by 10 $\mu g/m^3$ we would expect mortality to increase by 2.5 per cent.

[5] See minutes of the NO2 working group on the COMEAP website https://www.gov.uk/government/groups/committee-on-the-medical-effects-of-air-pollutants-comeap#minutes

10. It is important to stress that significant uncertainties remain around the quantitative link between exposure to NO_2 and the health impacts. The evidence in this area is still being reviewed by COMEAP's working group on NO_2. The working group noted that one of the uncertainties is in the extent to which the association between long-term average concentrations of NO_2 and mortality is causal. It is likely that some of the effect is due to NO_2, but other co-emitted pollutants could also be responsible to some extent. There is likely to be more uncertainty when the measure is specific for a reduction in NO_2, compared to when an intervention aims to reduce the whole mixture of air pollutants.

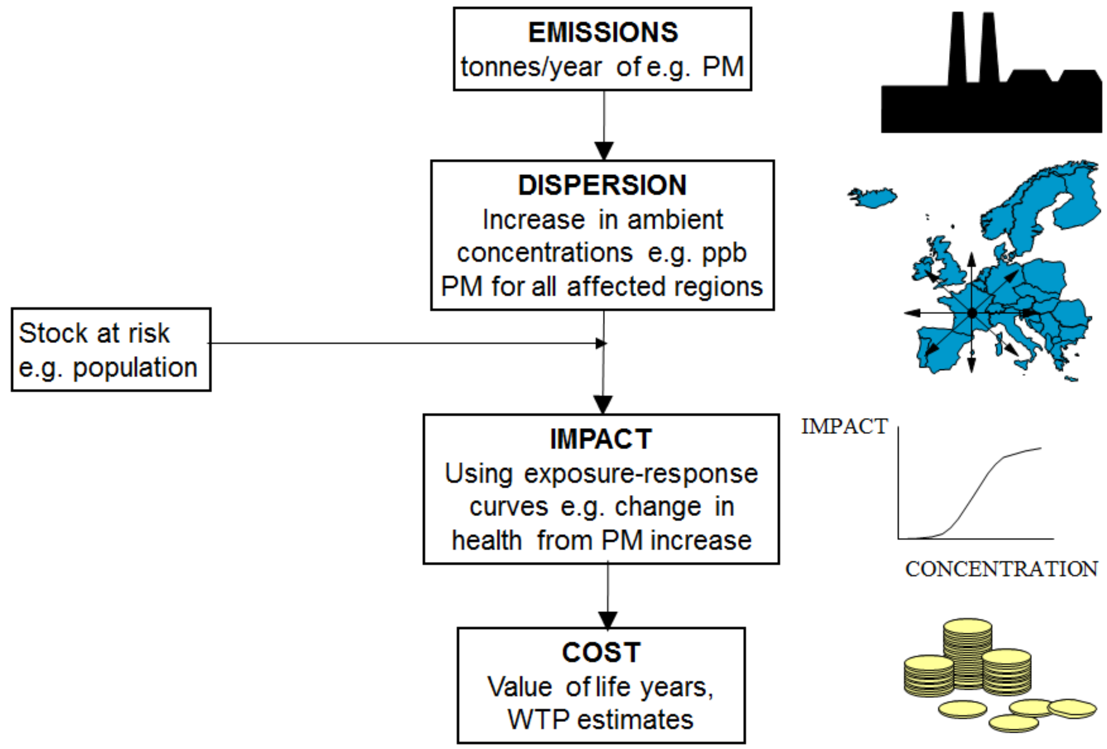
11. When the interim coefficient of 1.025 (1.01-1.04) is included in an assessment which also includes assessment of health impacts on the basis of particulate matter (PM), COMEAP recommend a reduction of the coefficient by up to 33% to take account of possible overestimation due to double counting of effects associated with PM.

12. The on-going review by COMEAP's NO_2 working group is intending to build upon its interim recommendations and to provide a clearer understanding of the quantitative link between NO_2 concentrations and mortality by undertaking a new meta-analysis. It will also consider the uncertainties and how the evidence should be used. However, given the significance of this development, and the plans currently being developed to improve air quality in the UK it was decided that the evidence linking NO_2 concentrations with mortality should not be ignored.

3. Updates to air quality valuation

13. In light of the developments set out in section 2, Defra is updating the recommended guidance on air quality appraisal. This change reflects the new evidence on the impacts of NO_2 on public health. These impacts are assessed through the impact-pathway approach (I-PA) illustrated in figure 1 below.

Figure 1: Impact-pathway approach



14. Following the interim recommendation from COMEAP the range of impacts estimated has been changed. Specifically we now recommend that for each 10 µg/m^3 change in exposure to NO_2 the mortality of the exposed population be reduced 2.5% within a range of 1% and 4%.[6]

15. The full I-PA modelling is relatively resource and time intensive. Therefore to support decision making, damage costs per tonne of emissions have been developed for use by analysts. These damage costs are derived from the full I-PA analysis. In this way they provide a proportionate approach to valuing of the impacts of changes in air quality.

[6] This refers just to the change in the health outcome and so is equivalent to the COMEAP co-efficient of 1.025 (1.01 – 1.04).

16. Based on this approach new damage costs have been estimated for emissions of oxides of nitrogen (NO_X). As the impact is associated with population-weighted NO_2 exposure it is no longer appropriate to provide a single national damage cost for NO_X. Therefore a range of damage costs have been estimated for different geographical locations. These areas are consistent with the geographical split for damage costs for particulate matter to minimise the annual burden in applying this update.

17. The key uncertainty around the impact of NO_2, and consequently emissions of NO_X, is the link to mortality. Therefore the range around the central estimate should reflect the recommended low (1%) and high (4%) coefficients. Table 1 provides the full list of the NO_X damage costs and the range around the central values.

Table 1: NO_X damage costs (per tonne, 2015 prices)

	Central	Low	High
Domestic	£14,646	£5,859	£23,434
Agriculture	£5,050	£2,020	£8,080
Waste	£10,858	£4,343	£17,373
Industry	£13,131	£5,253	£21,010
ESI	£1,263	£505	£2,020
Transport average	£25,252	£10,101	£40,404
Transport central London	£115,405	£46,162	£184,648
Transport inner London	£118,688	£47,475	£189,901
Transport outer London	£77,526	£31,010	£124,041
Transport inner conurbation	£61,365	£24,546	£98,184
Transport outer conurbation	£38,131	£15,253	£61,010
Transport urban big	£45,455	£18,182	£72,728
Transport urban large	£36,617	£14,647	£58,587
Transport urban medium	£28,788	£11,515	£46,061
Transport urban small	£18,182	£7,273	£29,091
Rural	£7,829	£3,131	£12,526

18. If the impacts of PM are also being quantified and valued for a policy, programme or project, then it may be appropriate to reduce the direct health impact of NO_2. In line with the COMEAP recommendation the NO_2 coefficient may reduce by up to 33%. Where a central estimate is required it is recommended that the coefficient is reduced by the average of this range (16.6%). Table 2 below provides the recommended NO_X damage costs for use where the impacts of both NO_X and PM are being valued.

Table 2: NO_X damage costs if PM is also valued (per tonne, 2015 prices)

	Central	Low	High
Domestic	£12,205	£4,882	£19,529
Agriculture	£4,209	£1,683	£6,734
Waste	£9,049	£3,619	£14,478
Industry	£10,943	£4,377	£17,508
ESI	£1,052	£421	£1,684
Transport average	£21,044	£8,417	£33,670
Transport central London	£96,171	£38,468	£153,874
Transport inner London	£98,907	£39,563	£158,251
Transport outer London	£64,605	£25,842	£103,368
Transport inner conurbation	£51,137	£20,455	£81,820
Transport outer conurbation	£31,776	£12,710	£50,842
Transport urban big	£37,879	£15,152	£60,607
Transport urban large	£30,514	£12,206	£48,822
Transport urban medium	£23,990	£9,596	£38,384
Transport urban small	£15,151	£6,061	£24,242
Rural	£6,524	£2,610	£10,438

19. More information on the application of these damage costs is provided in section 5 including a worked example.

20. The full I-PA modelling should be considered where proposals are expected to have impacts of more than £50 million, if the air quality impact is central to the policy in question or if the proposal affects compliance with legal obligations. If this applies to your proposal please contact igcb@defra.gsi.gov.uk for advice.

4. Consequences of this update

21. In addition to updating the way air quality should be valued to inform decision making this development has a notable effects on the assessment of the total impact of air pollution. This section provides an indicative estimate of the possible national impact of the prevailing rates of exposure to nitrogen dioxide (NO_2).

22. Following the impact-pathway approach (I-PA) the first stage is to estimate the ambient concentrations of NO_2. This has been estimated using national air quality modelling. The estimates used in this calculation are based on the latest reported concentrations in 2013.

23. The concentrations are then converted into an estimate of public exposure. This calculation is consistent with that currently used for PM, known as the population weighted mean exposure. The results of this are presented in table 3 below disaggregated by geographic region.

Table 3: Population Weighted Mean NO_2 Concentration ($\mu g/m^3$)

	2013
Scotland	11.429
Wales	12.459
Northern Ireland	8.875
Inner London	32.879
Outer London	25.121
Rest of England	17.077
UK	17.544

24. These exposure estimates can then be converted into health outcomes through the use of COMEAPs interim central co-efficient of 2.5%. This implies that on average the rate of mortality across the UK is approximately 4.3% higher as a result of the exposure to NO_2. Table 4 below converts this change in average mortality into annual equivalent attributable deaths and the quantified health impact.

Table 4: Health Impact from NO_2 (2013)

	Central (2.5%)	Low (1%)	High (4%)
Annual equivalent attributable deaths	23,500	9,500	38,000
Annual Social Cost	£13.3bn	£5.3bn	£21.4bn

25. Possible overlap between the health impacts associated with ambient concentrations of particulate matter (PM) and NO_2 need to be borne in mind when considering the above estimate. It is likely that there will be some overlap. Further work is being undertaken to understand and quantify this overlap but the current recommendation is that between 0 and 33% of the effects associated with ambient concentrations of the two pollutants overlap. Table 5 below provides an indication of the combined effect associated with these pollutants assuming that the two are completely independent.

Table 5: Total health Impact from PM and NO_2

	Impact
Annual equivalent attributable deaths	44,750 - 52,500
Annual Social Cost	£25.3bn - £29.7bn

5. Worked example of damage costs

26. Damage costs are a simple way to value changes in air pollution. They are estimates of the costs to society of the likely impacts of changes in emissions. Damage costs assume an average impact on an average population affected by changes in air quality. This is appropriate for small air quality impacts (below £50 million) provided your proposal does not affect areas likely to breach legally binding air quality limits.

27. In order to apply damage costs, it is necessary to first calculate the change in emissions due to the policy measure. The damage cost can then be applied to the change in emission, in order to estimate the monetary cost or benefit of the change in air quality. Full guidance for assessing this change can be found at www.gov.uk/air-quality-economic-analysis#damage-costs-approach.

28. The box below provides a worked example of how the health impact of NO_2 can be calculated for a hypothetical policy measure:

The hypothetical policy[7]:

A measure aimed at improving the efficiency of vehicles is to be introduced. One of the expected benefits of implementing this measure is the reduction of NOx emissions among other pollutants (e.g. impact on PM emissions). This measure is being assessed for 10 years, from 2016, and is expected to reduce emissions of NO_X by 12 tonnes per year until 2018 and 3 tonnes per year thereafter.

Step 1 – Identify and quantify reduction in emissions

The impact on emissions should be estimated on the basis of the amount of raw material used or processed at that source. The relationship between the raw material used and the pollution produced is known as the 'emissions factor'. For example, the emissions factor for road traffic is the amount of pollution produced per vehicle distance travelled. Estimates of emissions factors for different activities are developed by the National Atmospheric Emissions Inventory (NAEI). Their Emissions Factor Database is available here: www.naei.org.uk/emissions. The level of reduction that is expected in this hypothetical example is set out below.

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
NO_x Emission Reductions (Tonnes)	12	12	12	3	3	3	3	3	3	3

[7] Contact: igcb@defra.gsi.gov.uk for additional support as required.

Step 2 – Identify which damage cost values to use

Depending on the nature of the policy a sector-specific damage cost may be available. In this instance, as the hypothetical policy scenario relates to NO_2 emissions from vehicles, the NO_2 damage costs for transport average is therefore applied (see table 1). Damage costs are presented as a 'low' (1%) and 'high' (4%) estimates, to reflect COMEAP's current range of coefficients. Both of these will need to be considered to account for the range in value the air quality impacts are likely to have.

Starting with the central estimate, follow the workings set out below, and then repeat Steps 3 – 6 for the low (1%) and high (4%) estimates.

Step 3 – Convert NO_2 damage costs to base year prices

All the damage costs value presented in table 1 are in 2015 prices. These need to be adjusted to the baseline year for the policy/project appraisal (i.e. the year all costs and benefits are being compared against) to take into account inflation. In this case this is not necessary as the damage costs are already in the appropriate base year.

Step 4 – Uplift damage costs by 2% to reflect higher willingness to pay for health

This value now needs to be uplifted by 2% cumulatively per annum to reflect the assumption that willingness to pay for health will rise in line with economic growth. This is done by multiplying the damage cost with the uplift factor to reflect the annual increase. A worked example of this is shown in the table below. (If the analysis is also quantifying the impacts of PM, then it is recommended that the damage costs used in table 2 are applied).

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Damage Cost (£/tonne)	£25,252	£25,252	£25,252	£25,252	£25,252	£25,252	£25,252	£25,252	£25,252	£25,252
Uplift factor	1.02	1.04	1.06	1.08	1.10	1.13	1.15	1.17	1.20	1.22
Uplifted Damage Cost (£/tonne)	£25,757	£26,262	£26,767	£27,272	£27,777	£28,535	£29,040	£29,545	£30,302	£30,807

Step 5 – Calculate benefits for each year

The adjusted damage costs, calculated in Step 4, can be used to calculate the benefits of a reduction in pollutant emitted for each year of the appraisal period. This calculation simply multiplies the expected reduction in emissions figure from Step 1 (in tonnes) by the adjusted damage cost figure to calculate the annual benefit. This is shown in the table below.

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Emission Reductions (Tonnes)	12	12	12	3	3	3	3	3	3	3
Uplifted Damage Cost (£/tonne)	£25,757	£26,262	£26,767	£27,272	£27,777	£28,535	£29,040	£29,545	£30,302	£30,807
Benefits (£millions)	£0.31	£0.32	£0.32	£0.08	£0.08	£0.09	£0.09	£0.09	£0.09	£0.09

Step 6 – Discount benefits across the period of the policy appraisal and calculate total present value

To calculate the present value of air pollution impacts the undiscounted value of impacts for each year (calculated in Step 5 above) is simply multiplied by the discount factor below, where 1.035 is the 3.5% discount rate and *t* is the number of years into the future that value is from the base year (year 0):

$$\text{Discount factor} = \frac{1}{0.035^{t}}$$

Present value = Valued benefit x Discount factor

The table below shows the present values for the hypothetical policy scenario. The central estimate of the total present value of air quality impacts can then be calculated by calculating the sum of present values across the appraisal period. For this policy measure the central estimate is £1.34 million.

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Year (t)	1	2	3	4	5	6	7	8	9	10
Benefits (£millions)	£0.31	£0.32	£0.32	£0.08	£0.08	£0.09	£0.09	£0.09	£0.09	£0.09
Discount Factor	0.97	0.93	0.90	0.86	0.83	0.79	0.76	0.72	0.69	0.65
Present Value (£millions)	£0.30	£0.29	£0.29	£0.07	£0.07	£0.07	£0.07	£0.06	£0.06	£0.06

Repeat Steps 3 – 6 for the high and low estimate of damage costs

In order to calculate the high and low estimates, hypothetical policy scenario, steps 3-6 are repeated. The central estimate of the present value is £1.34 million. This gives a final estimate of expected present value of NOx air quality benefits of £0.54-£2.14 million.

COMEAP's coefficients	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Total
Central (2.5%)	£0.30	£0.29	£0.29	£0.07	£0.07	£0.07	£0.07	£0.06	£0.06	£0.06	**£1.34**
High (4%)	£0.48	£0.47	£0.46	£0.11	£0.11	£0.11	£0.11	£0.10	£0.10	£0.10	**£2.14**
Low (1%)	£0.12	£0.12	£0.12	£0.03	£0.03	£0.03	£0.03	£0.03	£0.02	£0.02	**£0.54**

Step 7 – Consider sensitivity analysis

Any policy, programme or project appraisals should include a sensitivity analysis alongside the total present value calculated in Step 6 above. Annex 1[8] of the Air Quality Damage Cost Methodology sets out the values that should be used to carry out the sensitivity analysis. These need to be applied using the same method set out in Steps 3 – 6 above to get a range.

Step 8 – Consider results alongside qualitative assessments

It is important to also consider any other impacts of a change in air pollution, in a quantitative or qualitative way, alongside the total present value. Such wider impacts can have a material implication for the decision made.

[8] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/182391/air-quality-damage-cost-methodology-110211.pdf