Updated emissions estimation method for diesel non-road vehicles and equipment

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ABSTRACT

Non-road emissions make up a substantial and increasing proportion of total emission loads in Australia, particularly in the absence of emissions standards, and have been poorly characterised to date. This paper discusses the recent update to the 2008 NPI combustion emission estimation method for non-road diesel engines (NPI 2008; NPI 2015), which applies the USEPA NONROAD model (USEPA 2010a). This method includes 3 important variables, which improve emissions estimation by better representing 1) the emissions standard to which the engine is compliant, 2) the transient use of the engine and 3) the deterioration of engine emissions over time.

An assessment of emissions standards, engine emissions data and activity data identified the USEPA NONROAD method as the most appropriate for use in Australia in the absence of local data. The Australian non-road population is unique and characterised by a small proportion adopting modern emissions control technology. Australia also has a greater proportion of large engines (>560 kW) than the United States and Europe. In addition, non-road engines in Australia are more intensively used compared to those in the United States or Europe.

Using 2008 population and activity data (NSW 2012a) emissions are estimated to increase by an average of 50% for uncontrolled engines and decrease an average of 80% for Tier 4 engines using the updated emission estimation technique (NPI 2015). A minimum emission performance for Australian non-road engines will only be achieved when national efforts to introduce emission standards and other measures to reduce emissions (e.g. retrofitting) take effect.

Keywords: *Non-road; Diesel engines; Emissions; Air pollution; PM.*

INTRODUCTION

Emissions from internal combustion engines contribute significantly to the deterioration of urban and non-urban air quality and have been identified as a risk to human health. In 2012 the International Agency for Research on Cancer (IARC) concluded that diesel exhaust is carcinogenic to humans and that gasoline exhaust is possibly carcinogenic to humans (Benbrahim-Tallaa *et al.* 2012). The agency particularly highlighted the increased risk of lung cancer from prolonged diesel exhaust exposure (Attfield *et al.* 2012; Silverman *et al.* 2012). As a consequence there has been a recent focus on quantifying diesel combustion engine emissions and their health impacts (Attfield *et al.* 2012; Benbrahim-Tallaa *et al.* 2012; Ristovski *et al.* 2012; Silverman *et al.* 2012). Diesel emissions from non-road engines are a substantial and increasing proportion of total emission loads in Australian rural and urban areas (NSW EPA 2012a; NSW EPA 2012b).

One of the primary contributors to this increased risk is the emission of fine particulate matter (PM2.5) from diesel exhaust, which is also related to a range of respiratory health outcomes such as asthma, lung function decrements and chronic obstructive pulmonary disease (Morawska *et al.* 2004; Ayres *et al.* 2008; HEI 2010; Ristovski *et al.* 2012). For instance, a 0.6 – 2.2 % increase in respiratory mortality risk has been estimated for each 10 μgm^{-3} increase in ambient particulate matter exposure (Pope and Dockery 2006).

This paper discusses the recently updated method for estimating combustion engine emissions for the National Pollutant Inventory (NPI), with a focus on non-road diesel engine sources (NPI 2015). In this study "non-road" is defined as diesel-powered equipment and non-road vehicles. This includes equipment and/or vehicles from the construction and surface mining general industrial, forestry and logging, light commercial and agricultural sectors (NPI 2015).

Non-road combustion emissions in Australia

Non-road combustion emissions in Australia are dominated by the mining and construction, agriculture and forestry, and general industrial sectors, with estimates of 60.5%, 30.2% and 7.9% of the national non-road PM10 emissions, respectively (PAE 2005; Environ 2010). Sales of new non-road engines are projected to grow by 3% per annum over the next 20 years, with the fastest growth in mining and construction and industrial sectors associated with increased output from mining and construction (Environ 2014).

NSW EPA (2012a) estimates that 86% of commercial and industrial non-road PM emissions are from non-urban areas in the greater metropolitan region of NSW, which encompasses Sydney, Wollongong and Newcastle. Coal mines have been estimated to be responsible for about 97% of these non-urban non-road diesel emissions (NSW EPA 2012a).

Non-road emissions are unregulated and they make up an increasing proportion of total emission loads in rural and urban areas. NO_x and PM2.5 emissions from Australian non-road diesel engines in 2012 were 171,900 and 18,850 tonnes per year respectively and are projected to increase by a factor of four by 2050 (Environ 2014). Health costs are predicted to increase from $690 million in 2012 to $4.6 billion by 2050 associated with increased non-road diesel emissions. PM2.5 concentrations are responsible for approximately 85% of these costs (Environ 2014). Capturing the emissions from non-road engines in the NPI dataset is important for population exposure assessment, which is increasingly important in national, state and local air quality management and policy development (NSW EPA 2015).

National Pollutant Inventory

The National Pollutant Inventory (NPI) is a national program that generates and maintains a free, publicly available database providing information on the location and quantity of 93 harmful pollutants emitted by major sources across the country. The Australian Bureau of Statistics has recently listed the NPI as one of the core statistical assets for Australia (Bureau of Statistics 2013). The focus of the NPI has traditionally been on quantification of industrial emissions, although recent projects have quantified national emissions at state level from other sources *e.g.* for shipping (Goldsworthy and Goldsworthy 2015) and motor vehicles (Smit 2014).

Facility operators estimate their own emissions and report them to state government agencies for verification and submission to the Commonwealth. This "bottom-up" approach to estimating non-road emissions has the capacity to characterise the spatial and temporal variation in non-road emissions. The NPI method relies heavily on industrial facilities accurately reporting their emissions.
To guide this process the NPI publishes Emission Estimation Technique (EET) Manuals. These manuals provide emission estimation methods for facility operators. The Combustion Engines EET manual is one of the most commonly used manuals as it applies across a large range of industries. This

paper outlines the recent update (NPI 2015) of the EET manual for Combustion Engines (HRL 2007; NPI 2008) to include up-to-date emission estimation methods for non-road diesel engines.

ESTIMATING NON-ROAD ENGINE EMISSIONS

The emission estimation methods adopted in the previous EET manual for Combustion Engines (HRL 2007; NPI 2008) are largely based on those listed in AP-42 (USEPA 1996), many of which have remained unchanged since their development in the mid-1970s (USEPA 1977). The emission estimation method used for non-road diesel emissions in the recently updated EET manual for Combustion Engines (NPI 2015) follows that used in the USEPA *NONROAD* model (USEPA 2010a). This method has also been used in recent assessments of non-road emissions for Australia (Environ 2010; NSW EPA 2012a; Environ 2014).

Equation 1 and Equation 2 show the annual emissions formulae applied in the updated NPI combustion emission manual (NPI 2015) for non-road mobile engines (USEPA 2010a).

$$E_i = P \cdot OpHrs \cdot LF \cdot PEF_{i,j} \cdot TAF_{i,j} \cdot DF_{i,j,k,l}$$

Equation 1

$$E_i = Q_f \cdot FEF_{i,j} \cdot TAF_{i,j} \cdot DF_{i,j,k,l}$$

Equation 2

Where:

- E_i is the annual emission of substance i [kg]
- P is the average rated engine power [kW]
- OpHrs is the annual operating hours of the engine [h]
- LF is the average load factor for the engine
- Q_f is the quantity of fuel combusted [L], and
- $PEF_{i,j,k}$ is the power based emissions factor of substance i, from engine compliant with emission standard j, with engine power k [kg/kWh].
- $FEF_{i,j,k}$ is the fuel based emissions factor of substance i, from engine compliant with emission standard j, with engine power k [kg/L].
- $TAF_{i,j}$ is the transient adjustment factor for substance i, from engine compliant with emission standard j, and
- $DF_{i,j,k,l}$ is the deterioration factor for substance i, from engine compliant with emission standard j, with engine power k and engine accumulated hours of use l.

Emission rates from combustion engines are a function of engine speed and torque (Abolhasani *et al.* 2008; USEPA 2010a; USEPA 2010b; Zhu *et al.* 2011; Abolhasani and Frey 2013). In addition, the emissions performance deteriorates with age, which can be aggravated by poor maintenance (Frey *et al.* 2010; USEPA 2010a; USEPA 2010b). The 2008 combustion engines EET manual did not account for the variation in emissions due to 'transient operation' (continuously varying engine speeds and loads in real world conditions) or the incremental increase in emissions over time due to engine deterioration.

The transient adjustment factor (TAF) is designed to account for the variation in emissions due to transient operation. In the *NONROAD* model TAFs have been calculated by comparing emissions from realistic transient test cycles with emissions from the non-road steady-state cycle (USEPA 2010a). In addition, Deterioration Factors (DFs) account for emissions increases over time due to engine wear, poor maintenance or tampering. Deterioration factors are particularly important for PM, and can lead to increased PM emissions of up to 47%, as compared to 10 – 18 % for CO, 3 – 5 % for HC and 1 – 2% for NO_x (USEPA 2010a).

Emission standards have driven the adoption of engine technologies aimed at reducing emissions from non-road combustion engines. The standard to which a given engine is compliant is a key variable for calculating engine emissions. The *NONROAD* model (Equation 1 and Equation 2) captures emission variability by incorporating a unique subset of emission factors for each emission standard. This variability is not captured by the method applied in the 2008 NPI EET manual (NPI 2008).

AN INTERNATIONAL COMPARISON OF NON-ROAD EMISSIONS

Ideally the non-road engine emissions estimation method adopted by the NPI would be based on emissions testing from Australian engines, however these data are scarce. The following sections describe the emission standards, activity data and emissions data from the United States (US), Australia and the European Union (EU). These comparisons were used to identify the most appropriate non-road emissions method for use in the updated NPI EET manual (NPI 2015). Differences between the three fleets and potential limitations to using overseas methods in Australia are highlighted.

Emissions Standards

Non-road diesel engine emissions standards from the US (USEPA 2010a; USEPA 2010b) and EU (EEA 2013) are widely referenced and commonly applied to non-road emissions regulation in countries throughout the world, although the regulation in other jurisdictions is generally lagging in time. US emission standards were introduced in 1996 (Tier 1) and have become increasingly stringent up to Tier 4 (finalisation in 2015). Similarly, European standard were introduced in 1999 (Stage I) and the most recent standard came into effect in 2014 (Stage IV). EU emission standards cover engines with rated power 19 – 560 kW. Emissions standards have tightened by up to an order of magnitude over time as shown in Figure 1. It is noted the US and EU standards are comparable because they use the same steady-state (non-transient) test procedure[1]. It is clear that information on the certification level of an engine is essential for proper selection of emission factors and estimation of emissions.

There are no non-road diesel engine emissions standards in Australia. In addition, publicly available routine emission testing is not undertaken for Australian non-road engines. Data on the in-use non-road population is therefore scarce, which impacts on the accuracy of emissions assessments.

Even in the absence of standards in Australia, improved technology available from

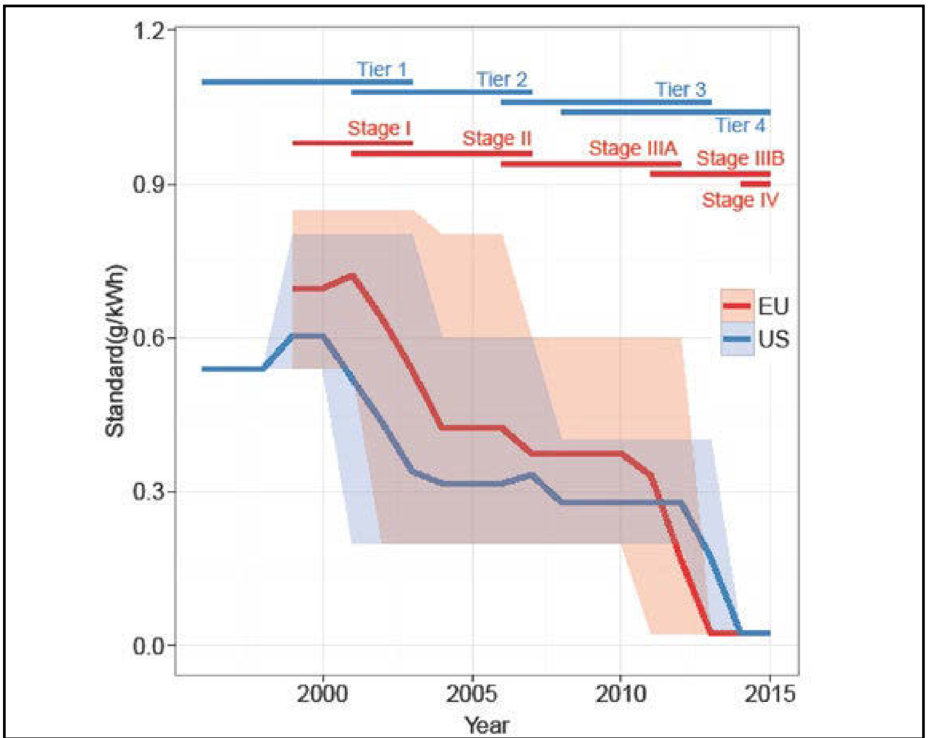

Figure 1: Non-road diesel PM emission standards for the US (blue) and EU (orange) up to 2015. Standards shown here are for 19-560 kW engines. Bold lines indicate the mean of standards for all engine power. Shaded regions are the range of standards for all engine classes. Horizontal lines show the period over which standards were in place.

the international market has penetrated into the Australian non-road population. Survey data indicate that approximately 36% of the diesel engines sold in Australia in 2008 were certified to an international emission standard by the appropriate authority (Environ 2010). The low level of certification in Australia means that emissions compliance must be estimated based on the engine model and year of manufacture. Table 1 shows the estimated proportion of non-road diesel engines sold in Australia in 2008 complying with US and EU emissions standards.

In 2008 Tier 3 to Tier 4 emissions standards were in place in the US and Stage III standards in the EU. Sales in Australia were still dominated by Tier 2/ Stage II engines at the time and a significant number of non-compliant and Tier 1/Stage I engines were purchased. This illustrates the lag in state-of-the art emissions performance for new engines in Australia in the absence of emissions standards.

Another key issue for non-road emissions reductions is scrappage and the continued use of old non-road equipment. In 2008, 56,246 non-road diesel engines were purchased in Australia, however it is estimated that 620,000 engines were in use (Environ 2010), highlighting the continued importance of emissions from older in-use engines.

Population and activity

Determining appropriate emission factors for Australian non-road engines requires careful consideration of the Australian engine population and their use. It is interesting to put the Australian situation in an international perspective. Four data sets were used to compare the application of non-road diesel engines in Australia, Europe and the US[2]. These are survey data of non-road engine use in greater metropolitan Sydney in 2008 (NSW EPA 2012a), USEPA *NONROAD* data (USEPA 2010c; USEPA 2010d) and activity data applied in the EU inventory guidebook (EEA 2013). The EU National Inventory Guidebook uses national engine population data from Denmark (Winther and Nielsen 2006) and Switzerland (Schäffeler and Keller 2008). The engine population, rated power, annual hours of use and load factors aggregated by equipment category are used to characterise engine use.

In comparison with the US and Europe, the Australian non-road fleet is dominated by high-powered engines, as is shown in Figure 2 and Figure 3. The US and EU populations are dominated by engines of between 37 and 100 kW (from 48 to 84%), whereas the Australian population is dominated by 100-560 kW engines (54%). There are a higher proportion of 100-560 kW engines in the US (18%) than in the EU (3-5%). Australia also has a large proportion of engines greater than 560 kW (22%). The absence of EU standards and therefore specific emission factors for engines greater than 560 kW presents a barrier to the use of EU emission factors in Australia.

In addition, the annual hours of use for Australian engines are significantly higher than for US, and particularly, European CI engines. Figure 3 highlights this. The median annual use for Australian engines is 901 hours, the usage drops to 622 hours per annum for US engines. EU engines are used even less intensively, with median annual use of 300 hours for Switzerland and 400 hours for Denmark. Operating an engine for more hours per year will lead to higher emissions due to deterioration of engine components.

To examine engine use in the 3 regions in more detail, individual equipment classes/ applications have been compared (Figure 4). For each equipment class the difference between Australian and US/EU population average engine operating power and annual use has been calculated. A positive difference indicates that the Australian fleet engine power or annual use value exceeds the US

US standard	EU standard	No. of engines equipment	% of engines/ equipment
Unknown		4978	8.9
Uncontrolled		6324	11.2
Tier 1	Stage 1	6171	11.0
Tier 2	Stage II	26474	47.1
Tier 3	Stage III	9439	16.8
Tier 4	NA	2860	5.1

Table 1: Emission compliance for non-road CI engines sold in Australia in 2008 (reproduced from Environ 2010).

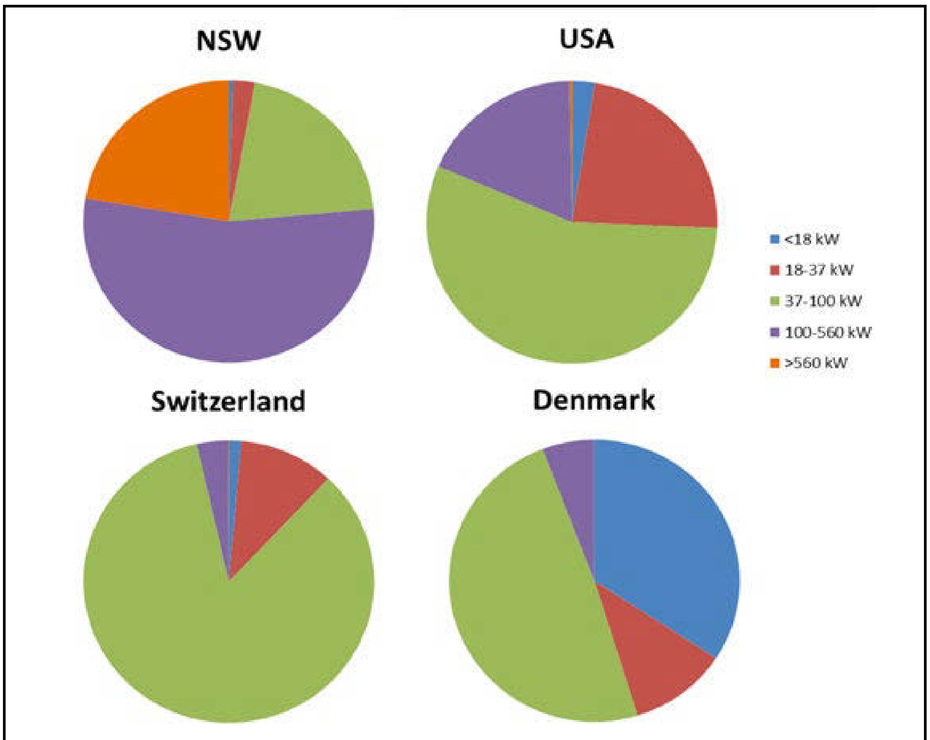

Figure 2: Proportion of non-road diesel engines by engine power in Australia (AUS), USA, Switzerland and Denmark.

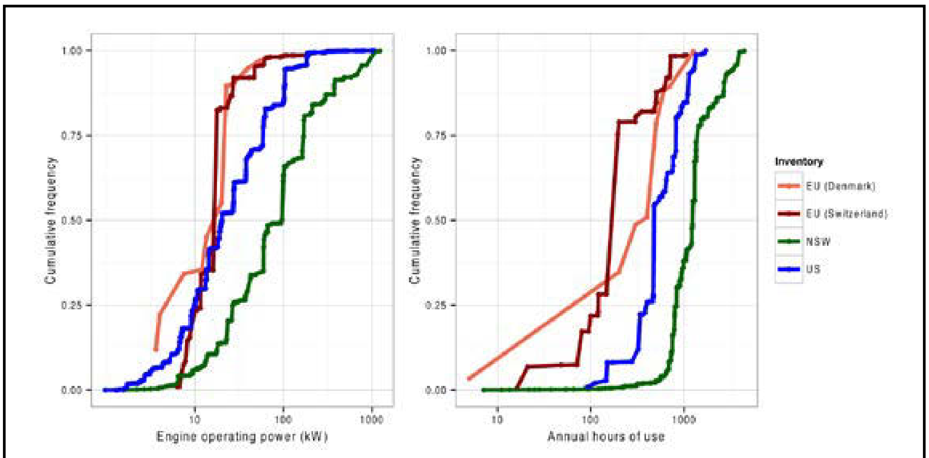

Figure 3: Cumulative distribution of engine operating power (rated engine power multiplied by load factor) (left) and annual activity in hours operated per year (right) for non-road engines in Denmark (Winther and Nielsen 2006), Switzerland (Schäffeler and Keller 2008), NSW (NSW EPA 2012a) and US (USEPA 2010d).

or EU values. The difference in engine size and annual hours of use between Australia and the other regions for each equipment class aligns with the data presented in Figure 4. The NSW inventory reports the largest average engine power and annual operating hours across the vast majority of applications. In addition the US dataset more closely follows that of NSW and in particular for applications requiring larger engine power and higher annual hours of use. It is noted that in a few cases (*e.g.* concrete/industrial saws) EU and US engines have a larger operating power and annual use.

Emission factors

Emission performance data specific to Australia would be preferential for use in emissions estimation. In the absence of these data international emission factors must be used. Differences between the USEPA *NONROAD* and EU emission factors relate to the use of local test data and the absence of EU standards for the smallest (<18 kW) and largest engines (>560 kW). In addition, transient emissions are not accounted for in EU emission factors up to Stage IV (EEA 2013).

Figure 5 compares US (*NONROAD*), EU and existing NPI (NPI 2008) CO, NO_x, PM2.5

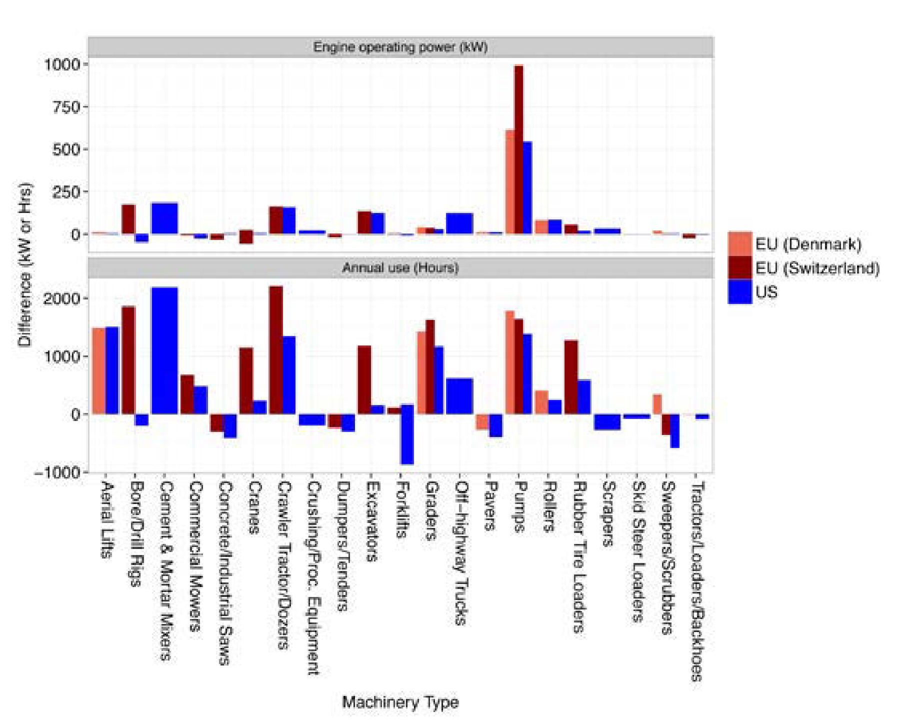

Figure 4: Difference between Australian and EU (Denmark and Switzerland) or US fleet engine size (top) and annual hours of use (bottom) for a selection of non-road equipment types.

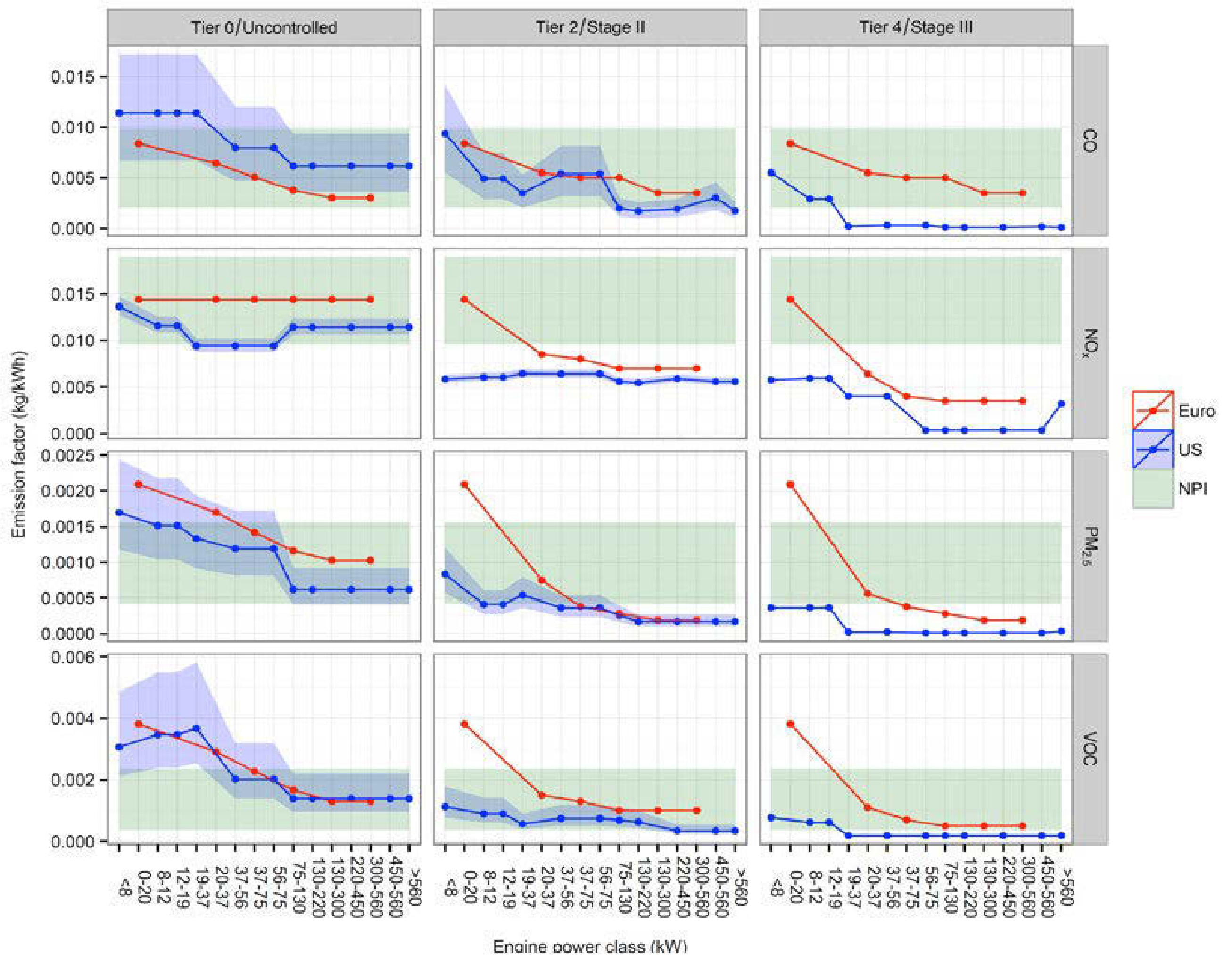

Figure 5: European, US EPA NONROAD and existing NPI (2008) CO, NOx, PM2.5, VOC emission factors for Tier 0/uncontrolled, Tier 2/Stage II and Tier 4/Stage III engines aggregated by rated engine power. Emission factors are calculated using an engine age of 0 hours at full load and a fuel sulphur content of 0.001 %. Green shading shows the range of emission factors for all industrial vehicles considered in the 2008 combustion EET manual. The average emission factor (blue circles) and range of emission factors (blue shading) for the three NONROAD TAFs are also shown.

and total volatile organic compounds (TVOC) emission factors (USEPA 2010a; EEA 2013). Variation in emission factors due to transient operation is apparent, the blue shading represents the variation in US emission factors at different loads. Low load factor transient use leads to increased emission factors particularly for uncontrolled engines. The US and EU emission factors deviate substantially from those in the existing NPI EET manual for engines compliant with the most recent emission standards, highlighting the importance of updating emission factors as new engines enter the non-road engine population.

The emission factors listed in the 2008 EET manual (USEPA 1996; NPI 2008) have largely remained unchanged since their development in the mid-1970s (USEPA 1977). *NONROAD* Tier 0 emission factors differ from those in the 2008 EET due to the inclusion of a larger and more recent set of test data (USEPA 2010a).

A preliminary assessment of the number of diesel engines sold in Australia in 2008 indicated that US standards are applicable to the majority of the Australian non-road fleet, approximately 95%, and EU standards to less than half, approximately 30% (Environ 2010). Australia has a very broad distribution of non-road engines, with a particularly large proportion of engines greater than 560 kW (Figure 3). USEPA *NONROAD* emission factors are more broadly applicable across engine categories and consider real world operation suggesting that they are the most appropriate emission factor dataset available for Australian conditions.

Default emission factors have been suggested based on conservative estimates of typical diesel engine age and emission standard compliance. Default emission factors are set at US Tier 0/uncontrolled levels. Tier 0 emission factors apply to engines with no available compliance information because facilities with engines adhering to the latest and strictest emissions standards are more likely to be aware of their emissions (Environ 2010).

The updated combustion emissions manual (NPI 2015) relies on emission factors developed in the US. Although this is regarded as the best available information at the moment, use of overseas data may lead to inaccuracies. For example the default engine age is assumed to be equal to the estimated life of similar engines, available from the *NONROAD* model. Engine life is estimated from the median life of US engines, this is the age at which 50% of the engines have been scrapped. Using the *NONROAD* method, engine deterioration is capped at this value *i.e.* the emissions performance for older engines will not continue to deteriorate in the model. It is uncertain whether using the median age of engines from the US and capping emissions increases at this age is appropriate for Australian conditions, particularly given the differences between the Australian and US non-road engine populations and usage shown in this study. An improved characterisation of the local non-road population, including emissions monitoring, is required.

It is clear that further updates will be required in the future to incorporate new data and information as time progresses, and to make further improvements to the NPI method. Of particular interest are potential emission measurements made in Australia, *e.g.* using portable emission measurements systems (PEMS) (Rubino *et al.* 2007; Fu *et al.* 2012). This would allow for targeted validation and subsequent updating of the new emission factors, better reflecting the impacts of local Australian conditions.

IMPACT ON EMISSIONS – A CASE STUDY

Consideration of engine emission compliance, deterioration and transient use in NPI (2015) will provide more accurate estimation of emissions for non-road engines. Figure 6 compares emissions from the 2008 EET manual (USEPA 1996; NPI 2008) with the updated emissions (USEPA 2010a; NPI 2015) for diesel engines. These emissions have been calculated using engine population, annual activity and rated power data from a 2008 survey of NSW industrial and commercial non-road engines (NSW EPA 2012a). Updated emissions were calculated assuming a set of TAFs based on those set out in USEPA 2010 and a sulphur fuel content of 10 ppm by weight.

Figure 6 shows three cases, in which the population is entirely made up of Tier 0, Tier 2 or Tier 4 engines. Figure 6 highlights the importance of emission standards, with updated EET (NPI 2015) emissions increasing from 2008 EET (NPI 2008) values by 50% on average (-100 to 400%) for uncontrolled (Tier 0) engines and decreasing by 80% on average (-99 to -10%) for Tier 4 engines. Updated *NONROAD* emissions (NPI 2015) are lower than the existing NPI emission estimates (NPI 2008) on average for Tier 1 to Tier 4 compliant engines. Updated emissions factors provide an improved representation of non-road engine emissions with an increasing number of Tier 1 – 4 compliant engines being added to the non-road population as Tier 4 emission standards come into full effect in the US in 2015.

The influence of deterioration as a function of engine age is clear for PM emissions, particularly from uncontrolled/ Tier 0 engines. For example, emissions from engines with rated power greater than 560 kW increased by up to 70 % after 7,000 hours of use at full load. Emissions deterioration decreases for engines compliant with more stringent standards. Emissions from >560 kW engines are higher than any other category, highlighting the importance of this class of engines in the Australian population.

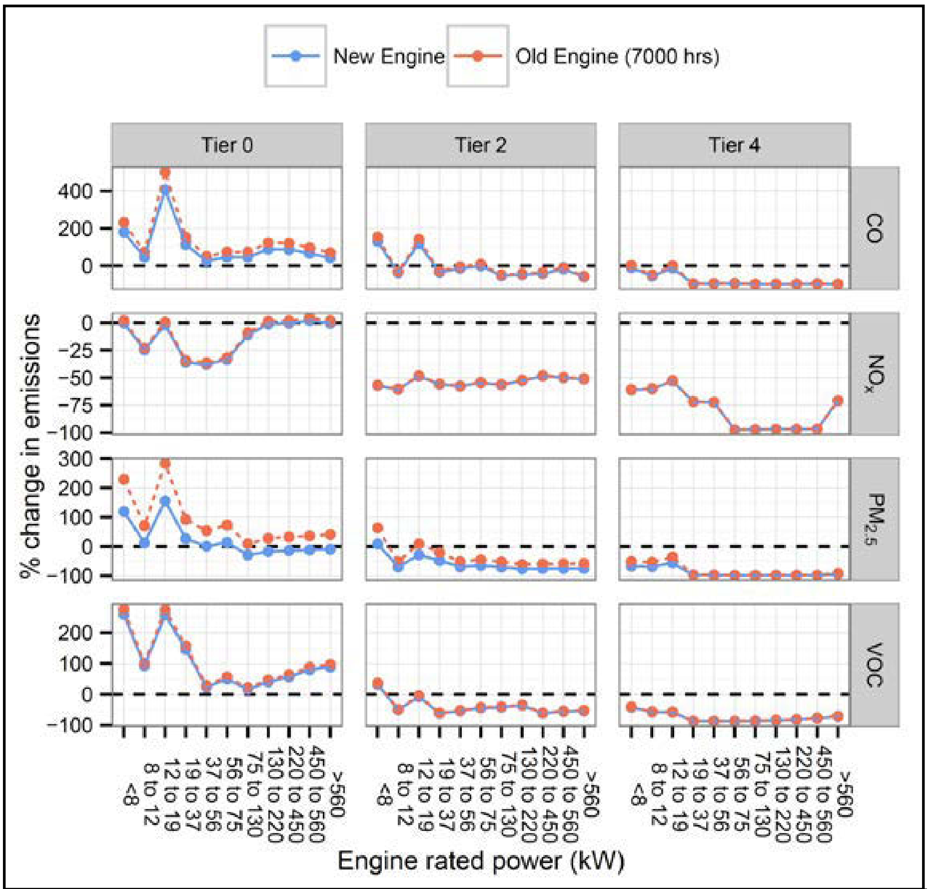

Figure 4: Percentage change in emissions of CO, NOx, PM2.5 and TVOCs between updated emission factors in this study and 2008 EET manual emission factors. Emissions are shown for industrial and commercial non-road diesel engines captured by the NSW 2008 survey data (NSW EPA 2012a). Emissions estimated after engine deterioration (7000 hours use at full load) are shown with a red dotted line. Percentage change calculated as the difference between updated emissions and 2008 emissions, as a fraction of 2008 emission factors. Dashed black line indicates no change in emissions.

CONCLUSIONS

Non-road emissions make up a substantial and increasing proportion of total emission loads in Australian rural and urban areas. As such these sources are important from an air quality and human health perspective. Typically, non-road diesel engine emissions are less well characterised than those from industrial or motor vehicles, primarily because of uncertainties in activity levels, locations and times of activity as well as emission factors.

Non-road emissions are regulated via emission standards in the US and throughout Europe. There are no equivalent non-road emissions standards in Australia. In-use non-road engines in Australia are sourced from the international market and as such their emission performance varies widely. The absence of emissions regulation, and therefore emissions testing, in Australia has created a void of information regarding the in-use non-road engine population. Limited understanding of the in-use non-road population provides a significant barrier to accurately estimate the exposure and health impacts of non-road emissions. This is of particular importance for adequate prioritisation of the different sources of air pollution (industry, shipping, motor vehicles, *etc*.) and subsequent policy development.

This paper discusses the recent update to the 2008 NPI combustion emission estimation method (NPI 2008; NPI 2015) to include the USEPA NONROAD method (USEPA 2010a). Updated emission factors include 3 important variables, which will enhance emissions estimation by representing 1) the emissions standard to which the engine is compliant, 2) the transient use of the engine and 3) the deterioration of engine emissions over time. The 2008 EET manual required the engine rated power, load factor, application and annual hours of use as input variables. In addition to these the updated method requires the engine emission standard compliance and total hours of operation over the engines lifetime (NPI 2015).

Comparison with international data makes it clear that the Australian non-road population is relatively old, with a small proportion adopting modern emissions control technology. Non-road engines in Australia are also more intensively used as compared with those in the US or the EU, which is relevant from an emissions performance perspective (deterioration). Finally, there is a larger proportion of large non-road engines (>560 kW) in-use in Australia.

The absence of engine testing data for Australia makes the selection of non-road engine emission factors a challenge and overseas information must be used. The US non-road engine population has characteristics closer to that of Australia than the European population. US standards (and therefore test data) also cover a broader range of engine power classes and importantly take engines with a rated power over 560 kW into consideration. The USEPA *NONROAD* model also incorporates transient operation and engine deterioration. Emission factors from the *NONROAD* model (USEPA 2010a) were therefore used to update the 2008 NPI combustion emission estimation technique manual (NPI 2008).

Emission factors in the updated EET manual (NPI 2015) better represent the variation in real-world engine emissions, with emission factors increasing from 2008 values by more than a factor of 2 for uncontrolled (Tier 0) engines and decreasing by up to a factor of 2 for Tier 4. Using 2008 population and activity data (NSW EPA 2012a), emissions increase by an average of 50% for uncontrolled engines and decrease an average of 80% for Tier 4 engines. The introduction of progressively more stringent international emission standards will increase the proportion of certified engines in the Australian non-road population. However, state-of-the-art emission performance for Australian non-road engines will only be achieved when national efforts to introduce emission standards and other measures to reduce emissions (*e.g.* retrofitting) take effect.

It is highly recommended that local emission measurement programs are conducted in Australia (*e.g*. using PEMS) to validate and update the overseas emission factors that are currently used. It is also important that the NPI manual is regularly reviewed and updated to reflect new policies and information.

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FOOTNOTES

1. Test cycles are used to measure the engine emissions performance and compliance with regard to emission standards. Engine speed and torque settings are predetermined to ensure that emissions from different engines can be compared. The test cycle for most US and EU non-road compression ignition engines is similar and uses a weighted 8-mode steady-state emission cycle (ISO 8178). It does not consider 'transient use' (USEPA 2010a). Emissions increase substantially during transient use, *e.g*. up to 2.1 times higher for PM emissions (Abolhasani *et al.* 2008; USEPA 2010a). The most recent standards (US Tier 4 and EU stage III/IV) both require the use of the non-road transient cycle (NRTC), which was jointly developed by the USEPA and EU authorities (USEPA 2010a). The NRTC defines a cycle of continuously varying engine speed and torque to account for real world operation. The cycle is run twice, a cold start and a hot start with a 20-minute soak period in between, and a weighting factor of 5% is applied to the cold start phase emissions (USEPA 2010a). Emission factors developed from steady-state test cycles require correction for use in inventories.
2. Activity data was obtained using a combination of survey and sales data in all jurisdictions. Commercial and industrial non-road engine equipment type, number and fleet composition for NSW was obtained from a survey of NSW Environmental Protection Agency licenced premises (NSW EPA 2012a). Non-road engine population estimates for the US are derived by applying the default scrappage curve to sales data (USEPA 2010a), activity data is based on surveys of equipment owners from which a mean usage rate for engines by application and fuel type is determined (Pechan 1997; USEPA 2010a). Similarly, EU activity data was based on questionnaires to manufacturers, importers and operators, and existing statistics, such as the database of the Swiss federal Motor Vehicle Inspection Office (Winther and Nielsen 2006; Schäffeler and Keller 2008). Small differences, such as the use of test data in the US to assign load factors, are unlikely to account for the deviations in engine population and hours of use.

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