Project Acronym and Title:

M4ShaleGas - Measuring, monitoring, mitigating and managing the environmental impact of shale gas

EU-BASED MODEL OF TRAFFIC RELATED IMPACTS

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Disclaimer

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Public introduction

M4ShaleGas stands for *Measuring, monitoring, mitigating and managing the environmental impact of shale gas* and is funded by the *European Union's Horizon 2020 Research and Innovation Programme*.
The main goal of the M4ShaleGas project is to study and evaluate potential risks and impacts of shale gas exploration and exploitation. The focus lies on the four main areas of potential impact: the subsurface, the surface, the atmosphere & climate, and public perceptions.
The European Commission's Energy Roadmap 2050 identifies gas as a critical fuel for the transformation of the energy system in the direction of lower CO_2 emissions and more renewable energy. Shale gas may contribute to this transformation.
Shale gas is – by definition – a natural gas found trapped in shale, a fine grained sedimentary rock composed of mud. There are several concerns related to shale gas exploration and production, many of them being associated with hydraulic fracturing operations that are performed to stimulate gas flow in the shales. Potential risks and concerns include for example the fate of chemical compounds in the used hydraulic fracturing and drilling fluids and their potential impact on shallow ground water. The fracturing process may also induce small magnitude earthquakes which may raise public concern if felt at the surface. There is also an ongoing debate on greenhouse gas emissions of shale gas (CO_2 and methane) and its energy efficiency compared to other energy sources
There is a strong need of a better European knowledge base on shale gas operations and their environmental impact particularly, if shale gas shall play a role in Europe's energy mix in the coming decennia. M4ShaleGas' main goal is to build such a knowledge base, including an inventory of best practices that minimize risks and impacts of shale gas exploration and production in Europe.
The M4ShaleGas project is carried out by 18 European research institutions and is coordinated by TNO-Netherlands Organization for Applied Scientific Research.

Executive Report Summary

This document introduces and summarises the 'Unconventional Hydrocarbons: Traffic Impacts Model Version 2 (TIMv2), which was produced as part of the M4ShaleGas Project, as part of a work-task examining the surface impacts of well site infrastructure. The text contained within this report also forms part of the M4ShaleGas deliverable "Final Report on the Impact of Well Site Infrastructure and Transport".

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1 INTRODUCTION

1.1 Context of M4ShaleGas

Shale gas source rocks are widely distributed around the world and many countries have now started to investigate their shale gas potential. Some argue that shale gas has already proved to be a game changer in the U.S. energy market (EIA 2015[1]). The European Commission's Energy Roadmap 2050 identifies gas as a critical energy source for the transformation of the energy system to a system with lower CO_2 emissions that combines gas with increasing contributions of renewable energy and increasing energy efficiency. It may be argued that in Europe, natural gas replacing coal and oil will contribute to emissions reduction on the short and medium terms.

There are, however, several concerns related to shale gas exploration and production, many of them being associated with the process of hydraulic fracturing. There is also a debate on the greenhouse gas emissions of shale gas (CO_2 and methane) and its energy return on investment compared to other energy sources. Questions are raised about the specific environmental footprint of shale gas in Europe as a whole as well as in individual Member States. Shale gas basins are unevenly distributed among the European Member States and are not restricted within national borders, which makes close cooperation between the involved Member States essential. There is relatively little knowledge on the footprint in regions with a variety of geological and geopolitical settings as are present in Europe. Concerns and risks are clustered in the following four areas: subsurface, surface, atmosphere and society. As the European continent is densely populated, it is most certainly of vital importance to understand public perceptions of shale gas and for European publics to be fully engaged in the debate about its potential development.

Accordingly, Europe has a strong need for a comprehensive knowledge base on potential environmental, societal and economic consequences of shale gas exploration and exploitation. Knowledge needs to be science-based, needs to be developed by research institutes with a strong track record in shale gas studies, and needs to cover the different attitudes and approaches to shale gas exploration and exploitation in Europe. The M4ShaleGas project is seeking to provide such a scientific knowledge base, integrating the scientific outcome of 18 research institutes across Europe. It addresses the issues raised in the Horizon 2020 call LCE 16 – 2014 on *Understanding, preventing and mitigating the potential environmental risks and impacts of shale gas exploration and exploitation.*

[1] EIA (2015). Annual Energy Outlook 2015 with projections to 2040. U.S. Energy Information Administration (*www.eia.gov*).

2 TRAFFIC IMPACTS MODEL

The Unconventional Hydrocarbons: Traffic Impacts Model Version 2 (TIMv2), has been developed by Newcastle University as part of the European Union Horizon2020 funded M4ShaleGas project. The model allows the calculation of a variety of environmental parameters (e.g. Greenhouse Gas Emissions, Local Air Quality Pollutants, Noise and axle loadings on roads, that arise from the traffic associated with 'unconventional' extraction of fossil-fuels (e.g. hydraulic fracturing for gas).

The first version of the model was implemented as part of the ReFINE (Researching Fracking in Europe) programme, and was described in a peer-reviewed article in the journal *Environment International*.

The URL for the model and accompanying website, hosted at Newcastle University is: http://research.ncl.ac.uk/uhtim. See Figure 1.

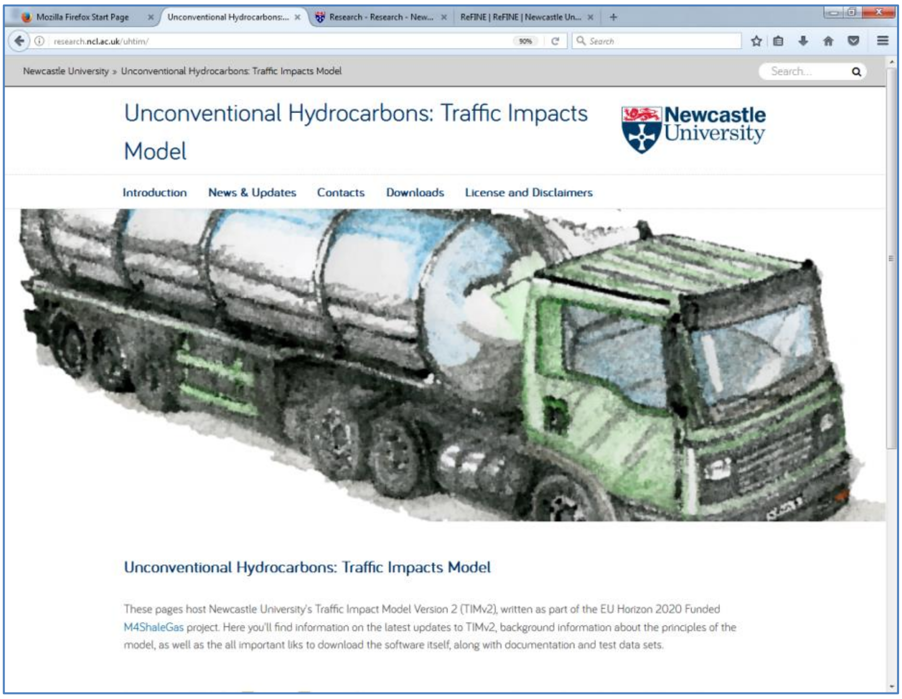

Figure 1. The Website for the Unconventional Hydrocarbons: Traffic Impacts Model Version 2 (TIMv2), hosted at Newcastle University.

2.1 Background

The report '*Review of Impact of Well Site Infrastructure*' *(NB: Link to external PDF)* of the M4ShaleGas project states that the exploitation of unconventional hydrocarbon resources will generate a variety of surface transport activities. These will occur at every stage of development: from initial exploration and test drilling, through production well development, through to final well-plugging and decommissioning. The primary, traffic-related, concern regarding hydraulic fracturing (colloquially 'fracking') activities is the possible use of large numbers of tankers and heavy trucks to transport the required volumes of water, sand and proppant materials. Likewise the removal of contaminated flowback liquids or produced water, may be problematic in the absence of adequate pipeline or recycling facilities, as these must then be tankered to water treatment facilities.

Surface transport activities have been identified as having an impact on the environment through:

- Greenhouse Gas (GHG) emissions (primarily CO_2);
- Emissions of gases that cause Local Air Quality (LAQ) issues (primarily NO_x/NO_2 and particulate matter);
- Creation of noise, and associated annoyance and disturbance;
- Damage to both road surfaces and road sub-structures, leading to cracking and 'pot-holeing';
- Congestion, disruption to other traffic, and community severance;
- Occurrence of incidents, accidents and spills;
- Light pollution.

Whilst ultimately adherence to regulations, best practice, sound prior planning, development of supporting infrastructure and improvements in technology may drastically reduce the need for, and impacts of, traffic activities, there remains the requirement to be able to assess the impact of operations in a holistic fashion – hence the development of the Traffic Impacts Model.

2.2 Components

The full TIMv2 application suite consists of seven, small executable files, compiled for the Windows operating system. Each of these executable files reads input from a particular directory (and sub-directories) associated with a given model run. Outputs from each stage of a model run (i.e. outputs from individual applications) are saved into sub-directories of the main. In that way, all inputs and outputs for a given run of TIM will exist, collated in the same location.

2.2.1 Application files

The individual applications and their functions are as follows:

1. ***M4InitialiseProject.exe:*** Takes a model run name and creates the main directory, and all required sub-directories for a given run. Also copies required pollution Look-Up Tables (LUTs) from the TIM installation location, to the main directory.
2. ***M4BaseTraffGen.exe:*** Takes a timetable of traffic events as input, and creates a ‘typical’ traffic pattern (flow only) for a week as output. The traffic patterns for an individual hour may be based on provided values (i.e. statically defined traffic on a particular road), based on traffic assignment (e.g. using ‘All-or-Nothing’,

'Incremental Loading' or 'Frank-Wolfe' cost-based assignments), or based on scaling data from another hour for which traffic has already been defined;

3. ***M4RegTimeGen.exe:*** Takes a timetable of events throughout the region, and collates them into a series of 'time-slices', with associated traffic patterns, that may be applied to the network in sequence;
4. ***M4FleetPollProc.exe:*** Calculates fleet-weighted LUTs for all used fleets ('Baseline' and 'SiteActive') using a 'palette' of vehicles. It is these fleet-weighted LUTs that are used in the final emissions calculations;
5. ***M4RegTraffGen.exe:*** Takes the baseline traffic pattern from 'M4BaseTraffGen.exe', and loops through the time slices provided by 'M4RegTimeGen.exe', to create traffic patterns (flows, speeds and costs on links) for a typical week in each time slice;
6. ***M4RegPollProc.exe:*** Uses the traffic patterns output from 'M4RegTraffGen.exe', combined with the fleet-weighted LUTs output from 'M4FleetPollProc.exe', and the time-slice durations output from 'M4RegTimeGen.exe' to produce 'Baseline' and 'SiteActive' emissions for the required pollutants in the period time-slices, and hourly values if necessary;
7. ***M4RegPostProc.exe (under development):*** Post-processes outputs from 'M4RegPollProc.exe' to give inputs appropriate for the 3rd Party ADMS (CERC, 2017) software.

2.3 Workflow

The full workflow through the individual applications, including the location of required input and output files is summarised in the Excel spreadsheet 'TIMv2_Workflow_190917.xlsx', provided on the downloads page of the website. Further information on each individual application will also be available in the forthcoming TIMv2 User Manual.

2.4 Sample datasets

The sample project provided with the TIMv2 downloads includes region, network and pad data, as used previously for example wells in the published *Environment International* article. The emissions factors are derived from a previous version of the DEFRA Emission Factors Toolkit (v5.1.3) and have been superseded by subsequent EFT versions (currently Version 7) in the UK.

2.5 Inputs

In order to model both the 'Baseline' and 'Sites Active' scenarios, the TIM requires a number of inputs. At the heart of the model is the concept of a 'region' – a spatiotemporal domain in which activities of interest occur. Inputs to the region include:

- The structure of the underlying road network in the region – both the physical locations and the 'types' of roads. The road 'type' determines how traffic speeds vary with traffic flow, and may also be used to determine different patterns of emissions;

- The baseline traffic, in terms of a weekly pattern of flow on the region's roads. If only limited data are available (e.g. only data from weekday peak periods), then appropriate scaling may be used to build a weekly pattern of flow;
- The position of well pad sites, a timetable of well pad activities, and the associated inbound and outbound flows of vehicles associated with each activity, for calculation of 'site-active' conditions.

Figure 2 shows an example region, its road network and well pad infrastructure. The road network carries the 'Baseline' traffic flows on defined road links. The well pads contain individual wells, each with their own plan of activities.

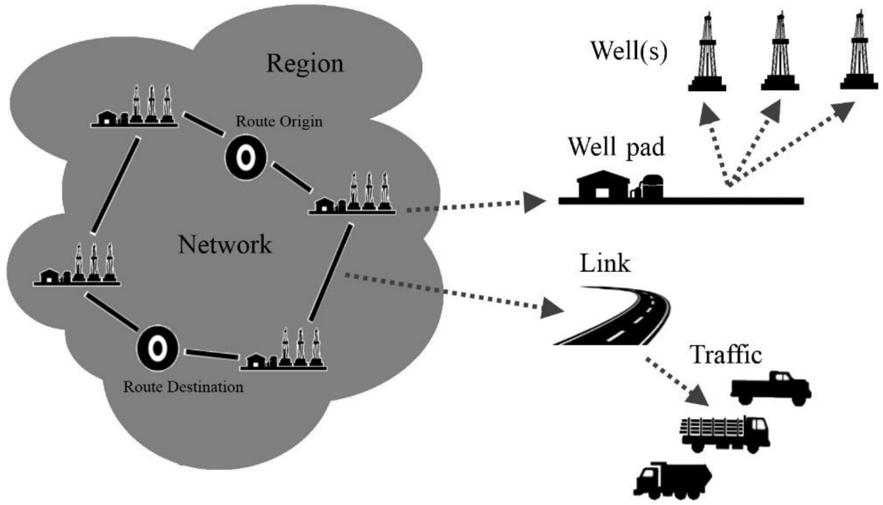

Figure 2. A region, with a road network and well pad infrastructure located within it. Source: Goodman et al. (2016).

Figure 3 shows the possible temporal trajectory for development of a well pad. Initial pad development and access road construction, is followed by rig mobilisation, well construction and initial drilling activities. After drilling, hydraulic fracturing may commence at each well. This is then followed by a period of removal of flowback and produced liquids, prior to well completion and operational production. The operational phase may last a number of years, but ultimately, the wells are capped to prevent leaks and contamination, and the pad is decommissioned. Each of these stages may involve different vehicles and timetables of activities within the TIM.

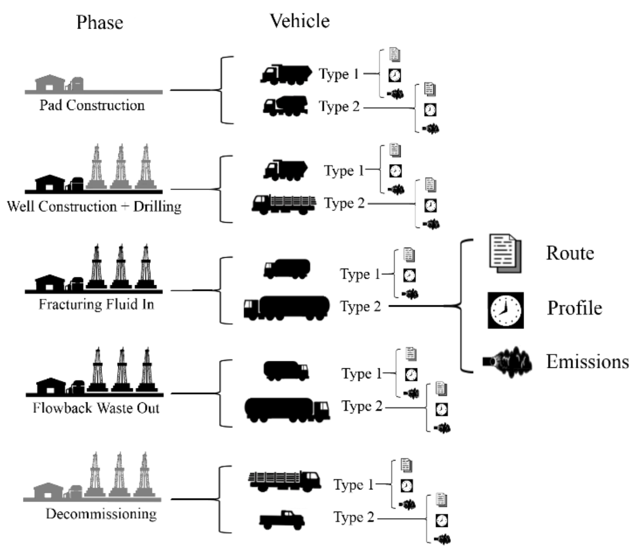

Figure 3. Pad and well activities generate traffic over a period of time. Source: Goodman et al. (2016).

The region concept, the structure of the road network, and the handling of well-pad activities is described in more detail in the *Environment International* article, as well as the (forthcoming) user manual for TIMv2, to be made available on this site. Inputs (and outputs) to (and from) TIM are generally in the form of text files, in comma-separated variable (csv) or structured JSON formats.

2.6 Outputs

Outputs from TIMv2 include greenhouse gas emissions (GHGs: uCO_2), local air quality emissions (LAQs: NO_x, NO_2, PM_{10}, $PM_{2.5}$, HCs), noise levels and axle loadings on roads. GHG and LAQ impacts being expressed as 'mass emissions' (i.e. grams, kilograms or tonnes of pollutant), noise being represented by a nominal roadside equivalent A-weighted sound level (L_{Aeq}) and road damage being expressed in Equivalent Standard Axle Loadings (ESALs). For air pollutants and ESALs, total emission values are given for both the 'Baseline' and 'Site Active' scenarios.

The figure below (Figure 1), taken from the *Environment International* article, demonstrates a 'Baseline'/'Site Active' comparison, in terms of percentage changes in pollutant totals, from a model of a six-well pad, developed over an 85-week period to completion, with all incoming and outgoing demands handled by tanker traffic. The type of road used to access the site makes a major impact on the relative increase in emissions. The selection of the length of the baseline period can radically alter the apparent increases in emissions (e.g. selection of the baseline over 'initial pad development to well completion' will give relatively larger increases than over 'initial pad development to decommissioning').

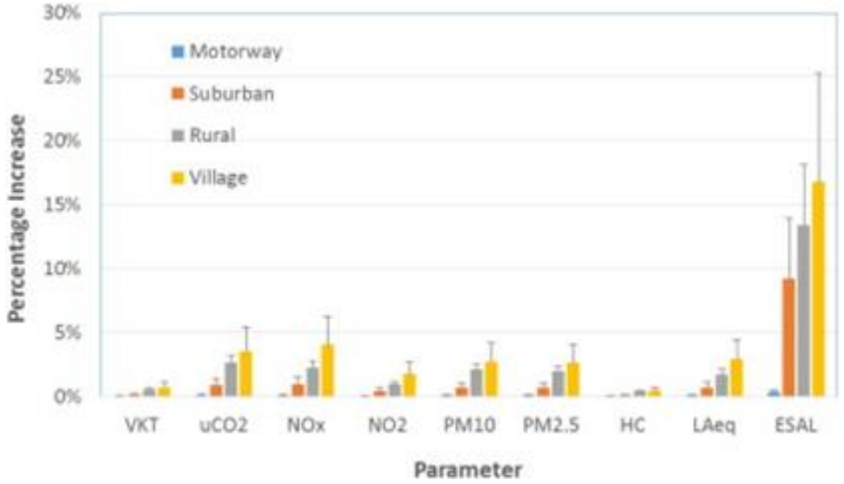

Figure 4. Percentage increases over baseline values for vehicle kilometers travelled, GHG and LAQ pollutants, noise and axle loading, assuming six-well pad operation using differing road types. Vertical bars show the difference between the ‘low-water use’ and ‘high-water use’ scenarios. Source: Goodman et al. (2016).

The ‘overall’ picture presented in Figure 4 does not reflect the fact that the *intensity* of operations may result in short-term, transient air quality issues. The greatest intensity of operations may be experienced during a well frack, when water demand is high over a period of several weeks. Figure 5, again from the *Environment International* article, demonstrates how the TIM can model changes in (NO_x) emission rates, during a short-term event, based on site access policy.

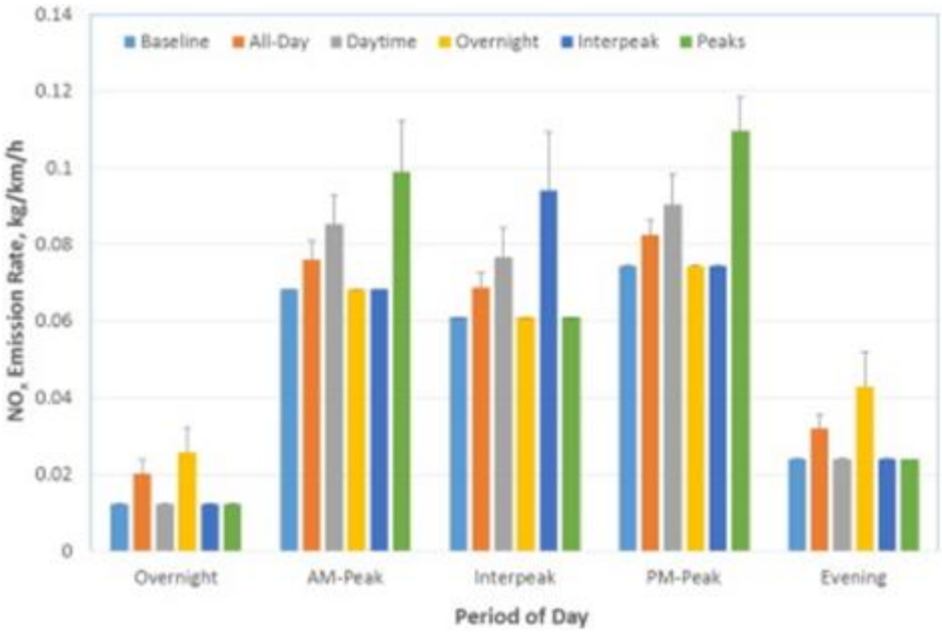

Figure 5. Peak operational NO_x emission rates compared to the baseline profile under differing vehicle arrival and departure policies. Source: Goodman et al. (2016).

For all outputs, totals may be broken down to the hourly level. This resolution is suitable for use in other models – e.g. for pollutant dispersion modelling in an appropriate, third-party package such as ADMS-Roads.

2.7 History

The original version of TIM was developed as part of the ReFINE programme, and was limited in only being able to use UK emission and fleet data. It could also only handle a single well pad, with up to twelve wells active on that pad, in a single model run. It was also limited to a four-year period of pad activities. Post-processing of multiple runs was required to collate data from multiple sites, over many years.

Version Two of TIM can potentially handle data from any country if presented in the correct format. It can also handle a large number of pads and wells, over a 50-year maximum period, if necessary. The trade-off for the increased flexibility of Version Two, is that run-times may be long, and a large number of intermediate and final output files may be produced.

Work is ongoing to improve the usability, flexibility, memory and disk requirements and run-time of TIMv2. Outside of M4ShaleGas activities, it is envisaged that future versions of TIM will feature:

- Enhanced run-times through multithreading of core calculation loops;
- Integration with Geographic Information Systems (GIS) to improve data entry, handling and visualisation;
- Better links to existing, third party air-quality modelling and noise mapping tools;
- Integration of health-related dose-response/impact-cost relationships for pollutants.

Whenever feasible, updates to TIMv2 will be made available via the 'Downloads' section of the Newcastle University website.

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