James Kallaos • Øystein Engebretsen
Iratxe Landa-Mata

SINTEF
NOTES
38

EE Settlement – Norwegian Model Description

THEORETICAL BACKGROUND, METHODOLOGY, REFERENCE VALUES, AND DATA SOURCES

SINTEF

SINTEF Notes

James Kallaos, Øystein Engebretsen and Iratxe Landa-Mata

EE Settlement – Norwegian Model Description

Theoretical background, methodology, reference values, and data sources

SINTEF Academic Press

SINTEF Notes 38
James Kallaos, Øystein Engebretsen and Iratxe Landa-Mata
EE Settlement – Norwegian Model Description
Theoretical background, methodology, reference values, and data sources

Keywords: EE Settlement; Embodied energy; Embodied emission; Mobility

ISSN 1894-2466
ISBN 978-82-536-1701-5 (pdf)

Project no: 102014481

Cover photo: James Kallaos

SINTEF Academic Press
SINTEF Community
Postbox 124 Blindern
0314 OSLO
Phone: +47 400 05 100
www.sintef.no/community
www.sintefbok.no

Preface

This report has been written within the research project *EE Settlement – Embodied Energy, Costs and Traffic in Different Settlement Patterns*, which is financed by The Research Council of Norway within the Byforsk programme. The project is a broad and interdisciplinary collaboration between SINTEF Community, Oslo Metropolitan University (OsloMet), the Norwegian Institute for Urban and Regional Research (NIBR) at OsloMet, Institute of Transport Economics (TØI), Kristiansand Municipality, National Association of Norwegian Architects - Norske Arkitekters Landsforbund (NAL) BYLIVsenteret initiative, and two partners from Vienna, Austria: Akaryon, and the Institute of Spatial Planning, Environmental Planning and Land Rearrangement (IRUB) at the University of Natural Resources and Life Sciences in Vienna (BOKU). The report is compiled with contributions from project partners as authors on the specific topics listed below:

Buildings and Infrastructure: James Kallaos (OsloMet and SINTEF)
Norwegian transport planning: Øystein Engebretsen (TØI) and Iratxe Landa-Mata (TØI)

The authors would like to thank the project partners for their contributions. The authors would also like to thank Selamawit Mamo Fufa and Kamal Azrague for their insights and direction. We also extend our thanks to Samuel Letellier-Duchesne (MIT) and Christofer Skaar (SINTEF) for their help with the EPD import tool, Knut Felberg (Kristiansand Municipality) and Terje Lilletvedt (Kristiansand Municipality) for their help with sourcing reference values, Peter Lichtenwöhrer (BOKU) and Georg Neugebauer (BOKU) for their work defining costs and services, and Hanne Liland Bottolfsen (SINTEF), Jørn Emil Gaarder (SINTEF), and Khin Su Su (Susan) Kyaw (OsloMet) for their contributions in the development of the *assemblies library*.

Oslo, Norway

28.04.2021

Maria Kollberg Thomassen	Selamawit Mamo Fufa
Research manager	Project manager
SINTEF Community	SINTEF Community

Abstract

Decisions regarding urban density and form present an ongoing challenge to European municipalities. The project *EE Settlement – Embodied Energy, Costs and Traffic in Different Settlement Patterns* specifically addresses some of the currently overlooked or unquantified aspects of new development projects (or settlements) – the embodied and operational energy, greenhouse gas (GHG) emissions, & direct public costs attributable to buildings, infrastructure, facilities, services, & transport. One output of the EE Settlement project is a web-tool designed to allow users to quickly assess and compare metrics regarding the embodied and operational energy, GHG emissions, and costs related to new settlements. The objective of this report is to provide an overview of the theoretical background, methodology, reference models, data sources, and limitations for the Norwegian model. This report is intended as a supplement to both the web-tool and the series of reports published under EE Settlement.

Sammendrag

Beslutninger om urban tetthet og form er en utfordring for europeiske kommuner. Prosjektet *EE Settlement – Embodied Energy, Costs and Traffic in Different Settlement Patterns* adresserer noen oversette eller ikke tallfestede aspekter ved nye utviklingsprosjekter eller bosetninger – energibruk, klimagassutslipp og direkte offentlige kostnader knyttet til bygninger, infrastruktur, anlegg, tjenester og transport. Et resultat fra EE Settlement-prosjektet er et internettverktøy som gjør det mulig å foreta raske beregninger av tall for energibruk, klimagassutslipp og kostnader knyttet til nye utviklingsprosjekter/bosetninger som grunnlag for sammenligning mellom ulike alternativer. Denne rapporten er ment som et supplement til både internettverktøyet og serien av rapporter publisert under EE Settlement. Målet med denne rapporten er å gi en oversikt over teoretisk bakgrunn, metodikk, referansemodeller, datakilder og begrensninger for den norske versjonen av modellen.

Contents

1. Overview

Arguments about density and form – and attempts at defining, measuring, and optimizing urban density and form – have a long history in urban planning. This often manifests as a mainly qualitative or visual discussion. The goal in the *EE Settlement – Embodied Energy, Costs and Traffic in Different Settlement Patterns* project is to bring a more robust quantitative analysis to the table and provide a tool that stakeholders can use to assess and compare some often-overlooked factors in the discussion.

Choices related to urban density and form – or settlement patterns - present a challenge to European municipalities, especially the seemingly basic discussion of what and where to build. The EE Settlement web-tool can help shine a light on some of currently overlooked or unquantified aspects of new developments – the embodied and operational energy, greenhouse gas (GHG) emissions, & direct public (at the municipal or local government level) costs attributable to buildings, infrastructure, facilities, services, & transport in new developments.

A series of reports have been published which provide insights on specific topics related to the project[1]:

1. *Embodied Energy, Costs and Traffic in Different Settlement Patterns: Background projects and tools.* SINTEF Research 61 (Fufa et al., 2019)
2. *Embodied Energy, Costs and Traffic in Different Settlement Patterns: Travel behaviour, housing and location preferences.* SINTEF Research 56 (Landa-Mata et al., 2018)
3. *Beregningsverktøy for bærekraftig by- og regionsutvikling: Identifisering av behov – workshop og intervjuer*. SINTEF Notat 32 (Venås og Mellegård, 2018)
4. *EE settlement – Norwegian case studies.* SINTEF Notes 39 (Fjellheim og Fufa, 2021)
5. *Bundet energi og klimagassutslipp i nye boligprosjekter. En veileder til beregningsverktøyet EE Settlement.* SINTEF Fag 76 (Barlindhaug et al., 2021)
6. *EE Settlement Final report.* SINTEF Research 77 (Fufa et al., 2021)
7. *User Guide EE Settlement* (Edelbacher et al., 2021)

This report is intended as a supplement to these other reports, and explains the theoretical background, methodology, reference models, data sources, and limitations for the Norwegian model. Much of the guidance for the development of the EE Settlement background model is based upon the framework described in the EE Settlement working paper outlining and defining the modelling task (Klinski, 2018).

The EE Settlement project simultaneously developed a model for Austria, which is also integrated into the web-tool. The differences in data availability between the two countries resulted in different approaches being developed for the background models supporting the web-tool – while the web-tool itself is adapted to seamlessly transition between the two countries. The Austrian team have included information about the Austrian background model in their upcoming Case Study Report (TBD, 2021).

It should be noted that the tool is intended to function optimally as a comparison tool between scenarios within the same country and should not be expected to function as an inter-country comparison tool, or for deducing specific accurate values for a single scenario. This is discussed in sections 3.5 and 4.3 related to limitations of the model.

This report will first present (Section 2) a quick summary of the expectations of the EE Settlement web-tool, and the role of the background model in the development of the web tool. Section 3 contains the technical guide for Buildings, Infrastructure, Services and Costs. The section concludes with a short discussion on limitations specific to that section. Section 4

[1] All reports are available on the SINTEF EE Settlement project website: https://www.sintef.no/projectweb/eesettlement/publications/.

presents an overview of the mobility model, and also concludes with a short discussion on limitations specific to that section.

2. EE Settlement web-tool and background model

2.1. Web-tool

The EE Settlement web-tool is the user interface for EE Settlement, integrating the background research, databases, and the resulting background model into an accessible web-based platform, or web-tool. The web-tool combines the background models for Norway and Austria, and for constructions and mobility, so that a seamless user experience is achieved. The constructions and mobility simulations are integrated into the web-tool but are intended to have a certain flexibility to allow for modifications, revisions, and updates from the background model.

As noted above, the EE Settlement web-tool considers the embodied and operational energy, GHG emissions, and direct public costs attributable to buildings, infrastructure, facilities and services in new developments, as well as residents' transport mode choice probabilities and energy and emissions associated to residents' car use (vehicle car kilometres). The buildings considered include both residential (section 3.3.2) and non-residential buildings (Sections 3.3.3 - 3.3.4). The infrastructure category includes surface infrastructure as well as the aboveground and underground infrastructure which may accompany the surface infrastructure (section 3.3.5). Specific services expanded or provided as part of the new development are included (section 3.4.2). Direct costs (initial investment and operations/maintenance) for specific categories which could be expected to be the responsibility of the local authority are estimated (section 3.4.3). Transport mode choices and car use are estimated for residents' journeys (trip chains) within the region starting in the planned settlement (section 4.2).

The specific tasks which the web-tool is designed to accomplish are:

1. Calculation of the embodied and operating energy of the buildings, associated infrastructure, and outdoor facilities,
2. Calculation of the embodied and operating GHG emissions of the buildings, associated infrastructure, and outdoor facilities,
3. Calculation of investment and operating costs for the associated infrastructure related to typical buildings and settlement patterns (not including the cost of the buildings themselves),
4. Estimation of energy demand, GHG emissions, and operating costs for associated services (e.g., waste disposal and snow removal activities),
5. Estimation of residents' travel mode choice probabilities, as well as energy use, and GHG emissions associated to residents' car use (vehicle kilometres) for regional journeys starting in the settlement,
6. Evaluation and presentation of results for each development,
7. Ability to compare two scenarios or settlements.

For specific technical considerations regarding the suer experience and interaction with the web-tool, the User Guide (Edelbacher et al., 2021) provides more information.

2.2. Background model

The background model serves as the basis for the development of the web tool. The background model is built in Excel and provides a platform for the researchers to assemble the data and underlying calculations. Specifically, the goal behind the development of the model framework and functioning background model was to provide a common framework for:

- A collaborative approach,
- Collecting research and sources,

- Determining relevant options,
- Adapting input data,
- Generating underlying calculations,
- Checking functionality,
- Providing uncomplicated integration with web tool.

As with all plans, the initial one required reformulation as the research progressed. The team realized at an early stage that the model for constructions (buildings and infrastructure) and the model for the mobility simulation need not be linked and could be developed separately by different researchers. As noted above, the Austrian team also developed their own background model using a different set of input parameters and approaches. Thus, several background models were developed, based on data availability and specific expertise, for different categories and in different countries. As noted above, this report covers the Norwegian approach.

The basic structure of the background model follows the flow chart below (Figure 2–1). Baseline values and user inputs in the model represent the minimum required knowledge needed about a project to run the model. The buildings, infrastructure, and mobility categories have different options, different methodological approaches, and different background data supporting them, which this report will address.

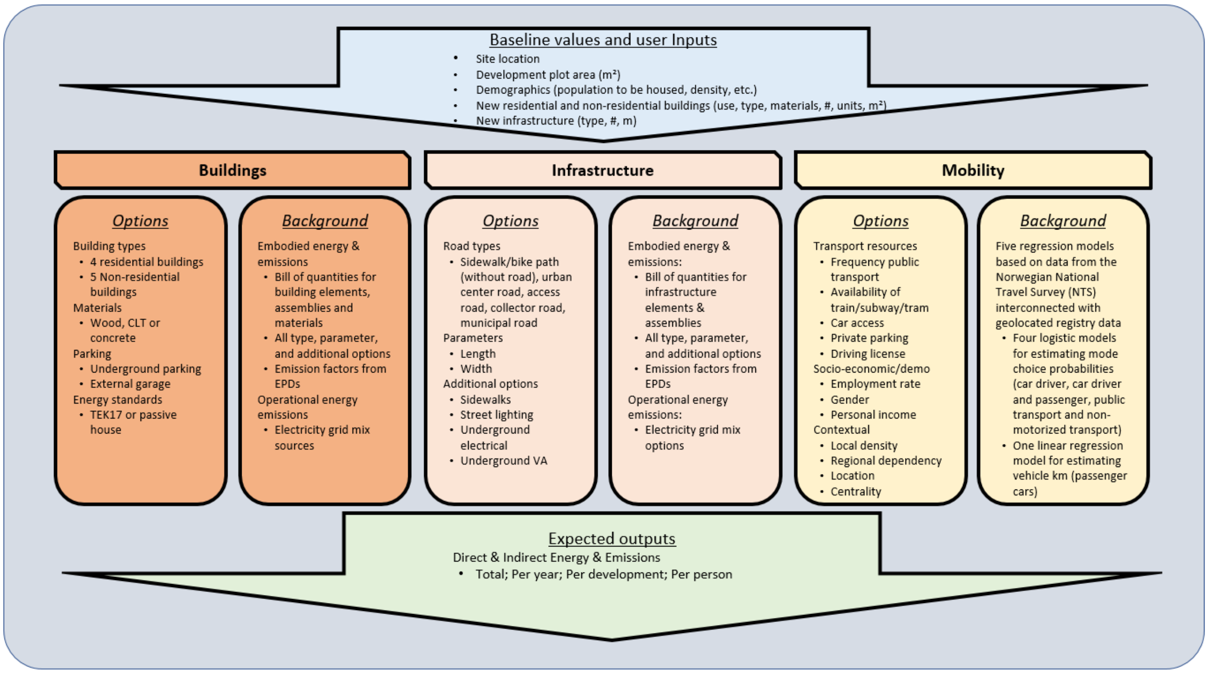


Figure 2–1. A schematic overview of the Norwegian EE Settlement background model (SINTEF).

3. Buildings and infrastructure

3.1. Model structure

The background model for buildings and infrastructure is built up from sub-categories and subsets of data libraries and calculation modules, depicted in the simplified diagram in Figure 3–1. Each of the six boxes within the background model is covered in detail in its own section following this brief introductory overview.

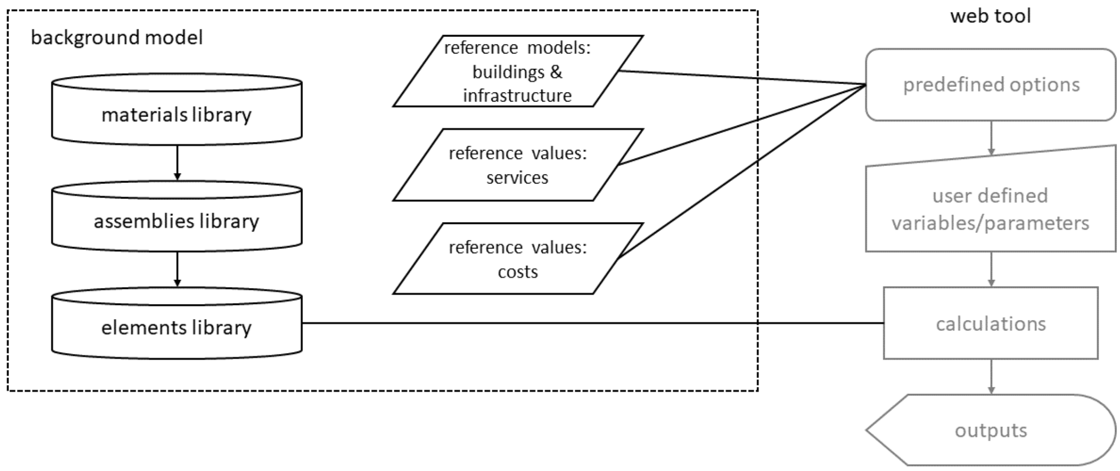


Figure 3–1. Simplified view of the roles of the background model and the web-tool.

Starting at the top left of the diagram in Figure 3–1, the *materials library* is a database containing embodied energy and GHG emissions data for each material used in the background model. The *materials library* is based on Environmental Product Declarations (EPDs). These materials are then built up into assemblies, contained in the *assemblies library*. While there is some overlap in assemblies between buildings, generally these are distinct entities. Each assembly comprises a set of layers with corresponding materials and thicknesses, normalized to a common unit which is relevant for the building or infrastructure element in question (usually m^2 per assembly). The *elements library* is simply a logically categorized collection of the summed embodied energy and GHG emissions values from each assembly.

Moving across the figure to the next set of data boxes, the reference models for buildings & infrastructure contain the algorithms for creating each construction from a limited set of user inputs. The algorithms allow detailed changes to the quantities of underlying elements (and therefore assemblies, and materials), depending on inputs. The reference values for services and costs lack the detailed background database of the reference models and are built to scale linearly with a limited set of inputs. This is covered in more detail in the relevant sections (3.4.2 & 3.4.3) as well as in the limitations section (3.5).

3.2. Libraries

The background model contains three "libraries" – one each for materials, assemblies, and elements. These libraries often contain sub-categories to delineate between different building or infrastructure types, or different options within each type-class. The following sections present simplified overviews of the actual libraries, covering the most important aspects of each library.

3.2.1. Materials library

The *materials library* contains a database of construction materials, combined with embodied energy (Cumulative Energy Demand, CED) and GHG emissions data. The library is mainly sourced from Norwegian Environmental Product Declarations (EPDs). The EPD database for EE Settlement used both manual import (line by line) of EPDs from portable document format (pdf) files, as well as through a custom import tool. The import tool was developed to allow the direct import of relevant data from the digi-norge EPD database (EPD Norge, 2021a). As of April 2021, about 60% of Norwegian EPDs are currently digitalized. The number is growing slowly as existing EPDs are digitalized, and old EPDs are retired and replaced with new digital EPDs. Where necessary, non-Norwegian EPDs were sourced to fill gaps in the existing Norwegian EPD database.

The following categories were built into the database:

1. EPD Category
2. Material group / product type
3. Product description
4. EPD reference number
5. UUID (universally unique identifier)
6. Issue date
7. Validity date
8. Product name
9. Producer
10. Geographical - production site
11. Geographical - market area / geographical representativeness
12. Electrical grid mix
13. Product density (kg/m^3)
14. Product thickness (mm)
15. Declared Unit / Functional Unit (quantity and units)
16. Reference Service Life (RSL)
17. Global Warming Potential GWP (kgCO_2eq/unit)
18. Cumulative Energy Demand CED(MJ/unit)

These categories are columns in an Excel file, with each material occupying one row. Revisions are made on separate worksheets, while retaining the integrity of the original download file. Several columns are added for conversions between units, for normalization, and standardization. Additional product subcategories are added to match the requirements of the defined assemblies.

Separate worksheets count and average the values for all the products within each defined sub-material group – those averaged values are supplemented with generic data for missing materials and provided as inputs to the *assemblies library*. The *assemblies library* is an input to the *elements library*. Only the *elements library* is transferred to be used in the web tool.

3.2.2. Assemblies library

The *assemblies library* contains the definitions for the layers that make up the different building and infrastructure elements. The library includes the layer definitions and thicknesses, the typical materials used for the layers (depending on building and material types), as well as other user-defined options (such as energy standard).

Dropdowns for material choices within the *assemblies library* link to the *materials library* and retrieve the average CED and GHG emissions values from the set of valid materials.

The assembly and element divisions for buildings mainly follow the Norwegian building element Standard 3451 (NS 3451:2009, 2009). The *assemblies library* for buildings was built using inputs from technical requirements such as TEK17 (DiBK, 2017) and the Norwegian Passive House Standard (NS 3700:2013, 2013), with technical guidance from the SINTEF Building Research Design Guides (Byggforskserien) (SINTEF, 2021), along with expert in-house consultation.

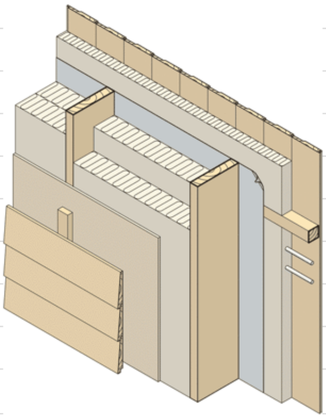
Assembly	**Label**	**Layer / Product**
External wall	A	Board (exterior wood cladding)
SFH & RH (Type 111 & Type 126)	B	Timber (solid wood)
Timber frame (TEK17)	C	Membrane (wind)
TEK17: ≤ 0.18 W/(m² K)	D	Timber (solid wood)
	E	Insulation (rock wool)
	F	Membrane (vapour barrier)
	G	Timber (solid wood)
	H	Insulation (rock wool)
	I	Board (interior gypsum)
	J	Layer / product
	K	Layer / product
	L	Layer / product
	M	Layer / product
	N	Layer / product
(SINTEF 523.255 2007, Figure v)		

Figure 3–2. An example of a wall assembly within the *assemblies library* in the background model.

The *assemblies library* for infrastructure uses different inputs for surface infrastructure (paths and roads) and underground infrastructure (water and power). Surface infrastructure is mainly based on handbooks from the Norwegian Public Road Administration (Statens Vegvesen Vegdirektoratet - SVV) (SVV, 2014a, 2014b, 2014c, 2016, 2018a, 2019), with some definitions based on the Kristiansand Kommune Veinormal (municipal road standard) (KrK, 2015) and inputs from other sources (VBT, 2015).

Underground infrastructure is generally based on guidelines in the SVV reports (SVV, 2019, 2018a, 2018b), guidance documents and standards for the Norwegian water sector (VA-Miljø, 2021), and interpretations of these rules (NIBIO, 2016; RVO, 2018). General definitions are found in the VA Norm (Water/Sewer Standard), which is adapted to different municipalities. The VA Norm for Kristiansand Municipality was used for some definitions (VA-Norm, 2019).

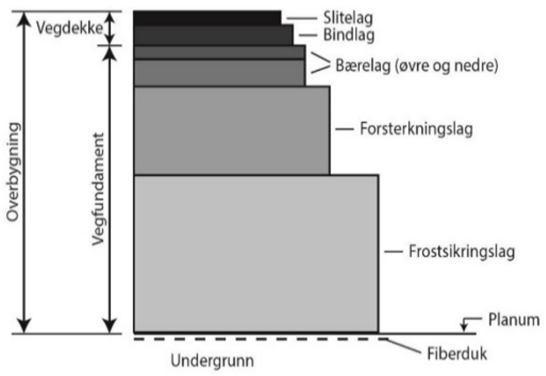
Assembly	Label	Layer / Product
Road (surface)	A	Asphalt (road wear layer)
Access road A1	B	Asphalt (road binding layer)
	C	Asphalt (road bearing layer)
	D	Asphalt (road levelling layer)
	E	Aggregate (crushed stone / kult)
	F	Membrane (geotextile)
	G	Layer / product
	H	Layer / product
	I	Layer / product
	J	Layer / product
	K	Layer / product
	L	Layer / product
	M	Layer / product
	N	Layer / product
(SVV 2016, p. 73)		

Figure 3–3. An example of a road assembly within the background model.

3.2.3. Elements library

The *elements library* is simply a collection of the summed embodied energy and GHG emissions values from each assembly, normalized to a unit which is relevant for the building or infrastructure element in question. Having these values (which are already calculated in the *assemblies library*) in one place provides several benefits. The *elements library* not only allows a quick visual scan for inconsistencies but serves as an easily updatable and exportable database for integration into the web-tool.

As noted above, the assembly and element divisions for residential and non-residential buildings follow the Norwegian Standard 3451 (NS 3451:2009, 2009):

- 21 Groundwork and Foundations
- 22 Superstructure
- 23 Outer walls
- 24 Inner walls
- 25 Floor Structure
- 26 Outer Roof
- 7 Outdoors installations (paved surface area and underground installations on the building site)

The divisions for infrastructure are presented in logical groupings:

- Road,
- Underground networks,
- Bus Infrastructure,
- Bike lanes & sidewalks.

3.3. Reference models: buildings & infrastructure

Reference models are a central part of the background model, forming the basis for the building and infrastructure calculations in the web-tool. Reference models are an inherent simplification of the real world, representing a simplified version of a structure or construction.

The goal of the reference buildings depends on the intent of the project – but are generally intended to "characterize the energy performance of typical building types under typical operations" (Deru et al., 2011, p. 8) or to approximate "buildings of the same type under the same conditions of use and climatic region" (Schaefer and Ghisi, 2016, p. 660).

Reference buildings can be grouped into 3 main categories:

1. "Example" - "…used when no statistical data are available … relies on the basis of experts' assumption and studies" (Corgnati et al., 2013, p. 985),
2. "Real" - "a real existing building, with average characteristics based on statistical analysis" (Corgnati et al., 2013, p. 985), and
3. "Theoretical" – "…a statistical composite of the features found within a category of buildings in the stock" (Corgnati et al., 2013, p. 985).

Regardless of the category, or the source of the data used, the purpose is to represent **typical** structures: "…the typical building geometry and systems, typical energy performance … typical functionality and typical cost structure…" (EU 244/2012, 2012, p. 20).

The EE Settlement project focusses on estimating embodied energy, emissions, and costs at the early planning phase. As a result, the chosen reference buildings represent a compromise between expected knowledge at the early design stage, computational simplicity, and data availability for both geometry and costs.

For residential and non-residential buildings, the default structures are shoebox models which mimic the building types - based on Norwegian Standard 3457 (NS 3457-3:2013, 2013), geometries, and materials found in the Norwegian Price Book (Norsk Prisbok) (Norconsult and Bygganalyse, 2021).

Reference models for infrastructure are historically less well-defined. As with buildings, the purpose is to represent **typical** structures. For the different infrastructure types available in the model, the default structures are "built" following guidance from a variety of sources, covered in more detail in the in the following sections.

3.3.1. Floor area definitions and the Common Area Factor (CAF)

The common area factor (CAF) for buildings, (Brutto-Netto Faktor, or BNF in Norway) is broadly defined as a factor calculated by dividing the gross floor area by the net (or functional, or program) floor area. Gross floor area (Bruttoareal, or BTA in Norway) is generally accepted as the numerator and consists of the entire area enclosed within the outer surface of the outer walls (or the middle of shared walls) (NS 3940:2012, 2012). There is no standardized approach to which format is used to define the denominator. Generally, the value used is summed "net floor area" (Nettoareal) which is defined as the internal area (defined per unit or section) inside the external walls, and excluding internal walls (Bånerud and Rudén, 2013a; NS 3940:2012, 2012). The actual values used in practice, however, can be vague and change depending on building type. Schools and public buildings often use NPA (net program area) in the denominator, where program area is defined as space needed per student (or employee, or patient) or per activity type. Offices may use FUA (functional area), and apartments projects can use BRA-S (sellable useful area). BRA is a Norwegian acronym for "Bruksareal" or "useful area" and is generally measured as a plane incorporating all area within the external walls where the ceiling height is more than 1,9m (DiBK, 2019; NS 3940:2012, 2012). BRA-S is that portion of the BRA which has market value (Siraj, 2015) (e.g., an apartment building consisting of ten 50 m^2 apartments has 500 m^2 of sellable area, regardless of the total building area).

Calculation of CAF/BNF does not appear to be an exact science and varies in usage between different fields. The common area is incorporated into the gross floor area of most buildings (besides single-residence homes, including row-houses), but excluded from the section-by section calculation of the "net" floor area. The common area often includes:

- Technical rooms and conduits,
- Construction area: Floor space used by common walls, columns, shafts, and the like, and
- Communication area: Common communication areas such as stairs, elevators, and other areas that connect separate areas.

Based on examples taken from the references in Table 3–A, the reference buildings used in the model have varying default CAFs/BNFs, ranging from 1 to 1,5. These are user editable.

Table 3-A. Examples of Common Area Factor (CAF) considered in different sources.

Building type	**Example**	**CAF/BNF**	**Source**
Residential			
Apartment block	ISY Calcus / Norsk Prisbok	1,3	(Bånerud and Rudén, 2013b)
Schools			
Barnehage	Trondheim Kommune (TK)	1,38	(TK, 2014, p. 33)
Barneskole 1-7	Trondheim Kommune (TK)	1,4	(TK, 2015, p. 44)
Ungdomsskole 8-10	Trondheim Kommune (TK)	1,4	(TK, 2015, p. 56)
Grunnskole 1-10	Båtsfjord skole	1,4	(Gloppen and Løtveit, 2018, p. 14)
	Haukås skole	1,4	(Løtveit and Bratholm, 2017, p. 14)
Videregående 11-13	Båtsfjord VGS	1,4	(Gloppen and Løtveit, 2018, p. 15)
	Mosjøen VGS	1,46-1,63	(NFK, 2017a, p. 45)
	Narvik VGS	1,55-1,76	(NFK, 2017b, p. 44)
Idrettshall/Gymnasium	Båtsfjord skole	1,25	(Gloppen and Løtveit, 2018, p. 15)
	Haukås skole	1,25	(Løtveit and Bratholm, 2017, p. 15)
	Trondheim Kommune (TK)	1,3	(TK, 2015, p. 70)
Office building			
Open plan	Concept for regjeringskvartalet	1,4	(Metier et al., 2013, p. 43)
Offices	Concept for regjeringskvartalet	1,45	(Metier et al., 2013, p. 43)

3.3.2. Residential reference buildings

The reference residential buildings are not static based on their initial definitions. The model provides a set of default values, but many values are user editable to create a custom scenario. Building defaults and options generally follow Norwegian guidance (DiBK, 2017) and the Norwegian market for new buildings.

Four different types of residential buildings can be added in the model in accordance with NS 3457 (NS 3457-3:2013, 2013):

1. SFH Single-family house 1-2 floors (Type 111 enebolig)
2. RH Row house (townhouse, terraced house) 2-3 floors (Type 126 rekkehus),
3. AB Apartment building 3-4 floors (Type 132 boligblokk på 3-4 etasjer),
4. TB Tall apartment block 5-8 floors (Type 133 boligblokk på 5-8 etasjer).

As stated above, the size and shape defaults are based on representative buildings in the Norsk Prisbok (Norconsult and Bygganalyse, 2021). The user is presented with six parameters (e.g., units, area, number of floors, etc.) and five building variables (e.g., options for garage, cellar, energy standard, etc.) with defaults based on the reference building.

Dimensions are calculated to fit the area and volume values presented in the Norsk Prisbok - but are generally not defined in the Prisbok. In most cases there could be several variations which would fit the values.

Table 3-B. Residential reference buildings - default geometries.

	SFH Single-family house (Type 111) 1-2 floors	**RH Row house (Type 126) 2-3 floors**	**AB Apartment building (Type 132) 3-4 floors**	**TB Tall apartment block (Type 133) 5-8 floors**
Cellar height (m) if added	2,7	2,7	2,8	2,9
Floor-floor height (m) non-cellar	3,0	2,7	3,09	2,8
Occupied floors (#)	1,5	2	3	7
Gross floor area (non-cellar) (m^2)	150	800	2250	4900
Cellar gross floor area (m^2) if added	100	400	750	1500
Building dimensions (width x depth, m)	10 x 10	44 x 9,1	75 x 10	50 x 14
Common area factor (CFA)	1	1	1,25	1,40
Total BRA Area (m^2)	150	800	1800	3500
Unit size (m^2 BRA)	150	200	60	50
Units per building (#)	1	4	30	70

Values are calculated as plausible options based on areas and volumes given. The unit size and the number of units per building are just one option of many. As discussed previously, the Prisbok is not explicit about assumptions regarding common area factor - which can have a large effect on units. In some cases, the limited information provided in the Prisbok is difficult to reconcile with simple shoebox-based reference models. To derive building dimensions which closely match the floor area, building volume, and outer wall area given, we assume a 1 m extension of side walls above the roofline for flat-roofed buildings, and 1,2 m extensions for the tall apartment (TB) block (1,2 m for buildings with total height >10 m), based on TEK17§12-15.3 (DiBK, 2017). The TB model in Prisbok is split into two sections. It is unclear why, or what the sections represent, but it is impossible to reconcile the surface areas and volumes listed without having multiple sections. The sections apparently do not cover the entire footprint, with the cellar floor area being about twice as large as the upper floors. The EE Settlement model does not follow the 2-section approach, instead using a single volume for estimations, which represents a significant deviation from the Prisbok approach.

Table 3-C. Residential reference buildings - model options and defaults. Defaults provided are in **bold red**, **while a** default with no other option is **bold purple**.

	SFH Single-family house (Type 111) 1-2 floors	RH Row house (Type 126) 2-3 floors	AB Apartment building (Type 132) 3-4 floors	TB Tall apartment block (Type 133) 5-8 floors
User inputs				
Dwelling units per building (#)	**1**	**4**, open choice	**32**, open choice	**70**, open choice
Living area per dwelling unit (m^2)	**150**, open choice	**200**, open choice	**60**, open choice	**50**, open choice
Number of floors (#)	**1,5**	**2** or 3	**3** or 4	5, 6, **7** or 8
Add a cellar?	unfinished cellar, **no cellar**	unfinished cellar, **no cellar**	**no cellar**, parking cellar*	no cellar, parking cellar*
Surface parking or external garage?	**external garage**, surface parking	**external garage**, surface parking	no garage or surface parking, **external garage,** surface parking	**no garage or surface parking,** external garage, surface parking
Building energy standard	**Current standard (TEK17),** Norwegian Passive House (N-PH)	**Current standard (TEK17),** Norwegian Passive House (N-PH)	**Current standard (TEK17),** Norwegian Passive House (N-PH)	**Current standard (TEK17),** Norwegian Passive House (N-PH)
Construction material	**Conventional timber frame**	**Conventional timber frame**	**Concrete frame, timber walls**, CLT (cross-laminated timber)	**Concrete frame, timber walls**, CLT (cross-laminated timber)

* If parking cellar is chosen, then "no garage or surface parking" is automatic.

3.3.3. Non-residential reference buildings – school buildings

The reference non-residential school buildings provide a set of default values, but many values are user editable to create a custom scenario. Building defaults and options generally follow Norwegian guidance (DiBK, 2017) and the "typical" expectations for new buildings in Norway.

Three types of non-residential school buildings can be added in the model in accordance with NS 3457 (NS 3457-3:2013, 2013):

1. N-KG Kindergarten - 1 floor (Type 612 barnehage),
2. N-PS Primary school - 1 floor (Type 613 barneskole),
3. N-SB Multipurpose sports building/hall (Type 651 idrettshall).

As stated above, the size and shape defaults are based on representative buildings in the Norsk Prisbok (Norconsult and Bygganalyse, 2021). The user is presented with different editable parameters with defaults based on the specific reference building.

Dimensions are calculated to fit the area and volume values presented in the Norsk Prisbok - but are generally not defined in the Prisbok. In most cases there could be several variations which would fit the values.

Table 3-D. Non-residential reference school buildings - default geometries.

	N-KG Kindergarten (Type 612) - 1 floor	**N-PS Primary school (Type 613) - 1 floor**	**N-SB Multipurpose sports building/hall (Type 651)**
Floor-floor height (m) (volume/area)	3	3,6	8,125
Occupied floors (#)	1	1	1
Gross floor area (non-cellar) (m^2)	800	3900	1660
Building dimensions (width x depth, m)	89 x 9	205 x 19	41,5 x 40
Common area factor	1,5	1,5	1,5
Total BRA Area (m^2)	535	2600	1107

Values are calculated as plausible options based on areas and volumes given. The limited information provided in the Prisbok is often difficult to reconcile with simple shoebox-based reference models. To derive building dimensions which closely match the floor area, building volume, and outer wall area given, we assume a 1 m extension of side walls above the flat roofline for the Kindergarten and Primary School buildings (N-KG and N-PS) based on TEK17§12-15.3 (DiBK, 2017). The Sports Building model in Prisbok appears to have a mezzanine over 25% of the ground floor area and is built 1 m belowground. The mezzanine and underground area are omitted from the EE Settlement background model and web-tool.

Table 3-E. Non-residential reference school buildings - model options and defaults. Defaults provided are in **bold red**, **while a** default with no other option is **bold purple**.

Type of non-residential building	**N-KG Kindergarten (Type 612) - 1 floor**	**N-PS Primary school (Type 613) - 1 floor**	**N-SB Multipurpose sports building/hall (Type 651)**
User inputs			
Program floor area (m^2)	**535**, open choice	**2600**, open choice	**1385**, open choice
Number of floors (#)	**1**	**1**	**1**
Parking lot or cellar?	**surface parking lot**	**surface parking lot**	**surface parking lot**
Building energy standard	**Current standard (TEK17),** Norwegian Passive House (N-PH)	**Current standard (TEK17),** Norwegian Passive House (N-PH)	**Current standard (TEK17),** Norwegian Passive House (N-PH)
Construction material	**Conventional timber frame**	**Conventional timber frame**	**Insulated sandwich**

3.3.4. Non-residential reference buildings – retail and office buildings

The reference non-residential school buildings provide a set of default values, but many values are user editable to create a custom scenario. Building defaults and options generally follow Norwegian guidance (DiBK, 2017) and the "typical" expectations for new buildings in Norway.

Two additional types of non-residential buildings can be added in the model in accordance with NS 3457 (NS 3457-3:2013, 2013):

1. N-RB Retail building (including cafe/market) - 2 floors (Type 321 kjøpesenter/varehus),
2. N-OB Office building - 4 floors (Type 311 kontorbygning).

As stated above, the size and shape defaults are based on representative buildings in the Norsk Prisbok (Norconsult and Bygganalyse, 2021). The user is presented with different editable parameters with defaults based on the specific reference building.

Table 3-F. Non-residential reference retail and office buildings - default geometries.

	N-RB Retail building (including cafe/market) (Type 321) - 2 floors	**N-OB Office building (Type 311) - 4 floors**
Cellar height if added (volume/area)	2,8	2,8
Floor-floor height (m) non-cellar (volume/area)	4,5	3,7
Occupied floors (#)	2	4
Gross floor area (non-cellar) (m^2)	4800	5000
Cellar gross floor area (if added) (m^2)	2400	1250
Building dimensions (width x depth, m)	49 x 49	58 x 21,5
Common area factor	1,5	1,5
Total BRA Area (m^2)	3200	3333

Values are calculated as plausible options based on areas and volumes given. The limited information provided by in the Prisbok is difficult (or impossible in the case of the Retail Building) to reconcile with simple shoebox-based reference models. To derive building dimensions which closely match the floor area, building volume, and outer wall area given, we assume a 1 m (1,2 m for total height >10 m) extension of side walls above the roofline for flat-roofed buildings based on TEK17§12-15.3 (DiBK, 2017). Cellars were not included in the specific retail or office building examples in prisbok used as templates for these reference buildings. The parking cellar previously defined for the 3-4 floor apartment building was used to estimate parking cellar dimensions and costs for both the retail and office buildings.

Table 3-G. Non-residential reference retail and office buildings - model options and defaults. Defaults provided are in **bold red**.

Type of non-residential building	**N-RB Retail building (including cafe/market) (Type 321) - 2 floors**	**N-OB Office building (Type 311) - 4 floors**
User inputs		
Program floor area (m^2)	**3200**, open choice	**3335**, open choice
Number of floors (#)	**2** or 3	**4**, 5 or 6
Parking lot or cellar?	surface parking lot, **parking cellar**	surface parking lot, **parking cellar**
Building energy standard	**Current standard (TEK17),** Norwegian Passive House (N-PH)	**Current standard (TEK17),** Norwegian Passive House (N-PH)
Construction material	**Concrete frame, concrete walls**, CLT (cross-laminated timber)	**Concrete frame, concrete walls**, CLT (cross-laminated timber)

3.3.5. Infrastructure reference models

Road categories and rules have changed in Norway in the past decade, from a system of named categories logical to non-experts, to a more flexible set of codified constructions. For example, the road categories with traditional or logical divisions (e.g., Access road, Collector Road, Main road), supplemented with letter-number codes, in the 2014 guideline (SVV, 2014d) have been replaced with only letter-number codes (e.g., H1, H5, H3) (SVV, 2019). These guidelines are translated into action by the municipalities when they develop their road guidelines (Veinormal), though at present many municipalities continue to use guidelines developed under the older SVV guidebook.

To maintain a logical connection between road options and road purpose, the current Road Guideline (Veinormal) for Kristiansand Municipality was used (KrK, 2015). The Kristiansand Veinormal offers a mix of old and new SVV rules, but in a logical format and with simple guidelines for sizing and traffic flow.

The model and web-tool incorporate a large set of options, the purpose of which is to allow a wide selection of road types instead of allowing the user to define road widths. The reasoning behind this that is that road assemblies do not scale linearly with road width, so allowing a user free reign to amend road widths would either require an unwieldy database and in-house calculations within the web-tool or would allow the creation of road surfaces which are not supported by the equivalent subsurface foundation.

Seven different types of surface infrastructure can be added in the model. As can be seen in Table 3–H (which shows a simplified version of the default base geometry for the different types of surface infrastructure), road width increases from access roads to collector roads and main roads, and roads noted with a 2 are smaller than those noted with a 1:

1. Sidewalk/bike path (without road)
2. Urban centre road
3. Access road A2
4. Access road A1
5. Collector road Sa2
6. Collector road Sa1
7. Main municipal road

The model includes the associated infrastructure connected to each surface infrastructure type, including underground (e.g., water, wastewater, electricity, etc.), and aboveground (e.g., streetlights, bus stops, sidewalks, etc.) networks.

Table 3-H. Surface infrastructure (roads) - default geometries.

Type of infrastructure	**Sidewalk/ bike path (without road)**	**Urban centre road**	**Access road A2**	**Access road A1**	**Collector road Sa2**	**Collector road Sa1**	**Main municipal road**
Road width (including shoulder) (m)	4	6,25	4,5	5,5	6	7	7,5
Sidewalk width (on each side of road) (m)		2,5	0	2,5	2,75	2,75	
Combined separate sidewalk/bicycle path width (m)			4	4	0	0	4

Road size should generally be determined by road type and the expected Annual Average Daily Traffic (ADT). Statistical ADT (Årsdøgntrafikk - ÅDT) in Norway can be visualized using the Vegkart tool from SVV and typing "Trafikkmengde" into the search box (SVV, 2021). Daily traffic estimations in the Kristiansand Veinormal follow a much simpler "rule of thumb" approach, where each residence is expected to generate an ADT of 7 (KrK, 2015). Estimations for required road sizing can therefore be generated while knowing only the road type and the number of residential units served.

Table 3–I and Table 3–J on the following pages show the model options and defaults for the different infrastructure types. The table is split into two parts for text clarity only.

Table 3-I**.** Infrastructure reference model options and defaults (split for clarity). Calculations presented in **bold green**, default in **bold red.**

Type of infrastructure	**Sidewalk/bike path (without road)**	**Urban centre road**	**Access road A2**	**Access road A1**
Road choice determined by road type and number of residential units (KrK)	Optional (not defined in KrK)	if relevant (not defined in KrK)	3<50 dead-end 3<100 loop	50<250 dead-end 100<250 loop
User inputs				
Number of residential units served (#)			Recommended ranges: **3-50 (dead-end)** 3-100 (loop)	Recommended ranges: 3-50 (dead-end) **3-100 (loop)**
Annual average daily traffic (ÅDT)*			**(7x # of units served)**	**(7x # of units served)**
Road length (m)	User input	User input	User input	User input
Road type		**Continuous**	**Dead-end**, Loop	Dead end, **Loop**
Include recommended street lighting?	**Yes**, no	**Yes**, no	**Yes**, no	**Yes**, no
Include sidewalk(s) on side(s) of road?		**both sides**, 1 side, no	both sides, 1 side, **no**	both sides, **1 side,** no
Include separate sidewalk / bicycle path?			Yes, **no**	Yes, **no**
Include bus pockets/refuges?				
Include underground drinking-, waste-, & storm-water network?		**Yes**, no	**Yes**, no	**Yes**, no
Include underground power network?	**Yes**, no	**Yes**, no	**Yes**, no	**Yes**, no

*Calculated using rule of thumb estimates from Veinormal for Kristiansand Municipality (KrK, 2015) - Annual Daily Traffic = 7x the number of residences served.

Table 3-J. Infrastructure model options and defaults (split for clarity). Calculations presented in **bold green**, default in **bold red** - default with no other option is **bold purple.**

Type of infrastructure	Collector road Sa2	Collector road Sa1	Main municipal road
Road choice determined by road type and number of residential units (KrK)	<250 total (including access roads served)	>250 total (including access roads served)	Optional (not defined in KrK)
User inputs			
Number of residential units served (#)	Recommended range: **<250**	Recommended range: **>250**	User input
Annual average daily traffic (ÅDT)*	**(7x # of units served)**	**(7x # of units served)**	User input
Road length (m)	User input	User input	User input
Road type	**Continuous**	**Continuous**	**Continuous**
Include recommended street lighting?	**Yes**, no	**Yes**, no	**Yes**, no
Include sidewalk(s) on side(s) of road?	**both sides**, 1 side, no	**both sides**, 1 side, no	
Include separate sidewalk / bicycle path?	Yes, **no**	Yes, **no**	Yes, **no**
Include bus pockets/refuges?	Yes, **no**	**Yes**, no	**Yes**, no
Include underground drinking-, waste-, & storm-water network?	**Yes**, no	**Yes**, no	**Yes**, no
Include underground power network?	**Yes**, no	**Yes**, no	**Yes**, no

*Calculated using rule of thumb estimates from Veinormal for Kristiansand Municipality (KrK, 2015) - Annual Daily Traffic = 7x the number of residences served.

3.4. Reference values

While not its main purpose (the EE in EE Settlement stands for Embodied Energy), the EE Settlement web-tool incorporates a limited subset of operational energy and associated GHG emissions data for public services for the new inhabitants, including operations and maintenance of public structures added in the development.

The EE Settlement web-tool also incorporates some limited, specific cost data, with the intention of providing an estimation of the direct public costs (to the municipality or other public agency) that should arise or be attributed to the new development/settlement.

3.4.1. Operational energy and emissions

The EE Settlement web-tool is specifically designed to assess embodied energy and GHG emissions from new development projects. Energy use in the operational phase is included but is not one of the most important aspects of the tool - it is treated only as a simple input to be determined by the building energy standard.

Operational energy consumption for different building types and energy standards are included in the web tool with default values that can be easily overridden by the user. Beyond the different materials (with different embodied energy and GHG emissions) used to fulfil the different energy standards, there is no other physical connection between construction site, building form, window area, or other aspects of the tool with the calculation of operational energy use. There is already a wide range of existing tools available to provide use-phase energy calculations, but the utility of engaging these tools at the early planning phase is debatable.

Table 3-K. Default reference values – operational energy

Building Type	TEK17	Passive House (PassivHus)	Unit	Reference / Source
Residential				
SFH Single-family house (Type 111)	111	59	kWh/m²/yr	(DiBK, 2017; NS 3700:2013, 2013)
RH Row house (Type 126)	102	59	kWh/m²/yr	As above
AB Apartment building (Type 132)	95	59	kWh/m²/yr	As above
TB Tall apartment block (Type 133)	95	59	kWh/m²/yr	As above
Non-Residential				
N-KG Kindergarten (Type 612)	135	59	kWh/m²/yr	As above
N-PS Primary school (Type 613)	110	59	kWh/m²/yr	As above
N-SB Multipurpose sports building/hall (Type 651)	145	59	kWh/m²/yr	As above
N-RB Retail building (including cafe/market) (Type 321)	180	59	kWh/m²/yr	As above
N-OB Office building (Type 311)	115	59	kWh/m²/yr	As above

The default electrical grid mix and corresponding GHG emissions (Table 3-L) are based on the estimated average value for the European Union and Norway (EU28 + NO) from 2015 to 2075, as defined in Norwegian Standard NS3720 (NS 3720:2018, 2018). This value corresponds well with the current "total supplier mix" in Norway in 2019 (AIB, 2020) assuming a gradual decarbonization of the electrical grid mix into the future (Dokka, 2011; Graabak and Feilberg, 2011).

Table 3-L. Default reference value – energy grid mix emissions

Electrical Grid	GHG emissions	Unit	Note	Reference / Source
EU28 + NO	0,136	$kgCO_2eq/kWh$	Reference timeframe: 2015 - 2075	(NS 3720:2018, 2018)

3.4.2. Public services

Included in the tool are operational energy, GHG emissions, and costs data for public services (those expected to be provided by the municipality or other public agency) that result from the new inhabitants or the new development/settlement. The services included in the tool can be divided into several categories:

1. Water: freshwater supply and distribution, and wastewater collection and treatment,
2. Solid waste: collection and treatment,
3. Road service: operations and maintenance.

Services: Water

Granular data for energy use in the supply and distribution of freshwater, and the collection and treatment of wastewater, was unavailable from Norwegian statistical databases. Estimations were made based on a short research note presenting an energy use study conducted by Asplan Viak for Norsk Vann[2] - using data from 2014 (Larsen, 2016). The values reported in the research note are modified using population data (SSB 07459, 2021) as well as water volume data (SSB 04936, 2021) reported for 2014. The resulting calculated values are in in the range

[2] Norsk Vann (Norwegian Water) is a national association representing Norway`s water industry.

expected when compared with academic papers assessing the life cycle energy use of the Trondheim and Oslo water systems (Slagstad and Brattebø, 2014; Venkatesh and Brattebø, 2011). The values used are not the most recent, but currently appear to be the best available to the public.

Table 3-M. Default values - water services

Services: Water	Value	Unit	Note	Reference / Source
Annual household water use per person	65,7	m^3/person/yr	(2020 value for household water supply per person) [180 liters/day]	(SSB 11787, 2021)
Electricity demand per m^3 water supply	0,52	kWh/m^3	Calculated for municipal water supply (private water excluded, though minimal effect)	Data from (Larsen, 2016) modified with (SSB 07459, 2021) and (SSB 04936, 2021)
Annual household sewage per person	65,7	m^3/person/yr	Estimated as equal to supply[3]	(SSB 11787, 2021)
Electricity demand per m^3 sewage	0,58	kWh/m^3	Calculated for municipal water supply (private water excluded, though minimal effect)	Data from (Larsen, 2016) modified with (SSB 07459, 2021) and (SSB 04936, 2021)

Services: Solid waste

As solid waste disposal in Norway can be net energy positive, depending on system boundaries, consisting primarily of incineration with energy recovery (Lausselet et al., 2017), the entire waste life cycle is not calculated in the web-tool. Only energy and emissions related to the fuel use of the service vehicles over the distance added to the development is included (this approach omits many important aspects – see section 3.5 for a discussion of limitations). The distance travelled is calculated from the roads added in the web-tool, while the collection frequency and vehicle type (and fuel use) are estimated. The reference values in the web-tool are the quantities of each waste fraction estimated for each inhabitant of the new development/settlement.

[3] This assumption ignores both leakage and infiltration, which represent large values in the existing Norwegian water network (Slagstad and Brattebø, 2014; SSB 11787, 2021; Venkatesh, 2011). Leakage and infiltration are neither estimated nor attributed to users in the EE Settlement model.

Table 3-N. Default values - solid waste disposal

Services: Solid waste	Value	Unit	Note	Reference / Source
Residual waste	0,170	tonnes/ person/ year	Household waste fraction divided by population	(SSB 07459, 2021; SSB 13136, 2021)
Bio waste	0,036	tonnes/ person/ year	As above	As above
Plastic	0,010	tonnes/ person/ year	As above	As above
Used paper	0,041	tonnes/ person/ year	As above	As above
Glass	0,013	tonnes/ person/ year	As above	As above
Used metal	0,019	tonnes/ person/ year	As above	As above
Bulky waste	0,015	tonnes/ person/ year	As above	As above
Tree clipping, lawn clipping	0,087	tonnes/ person/ year	As above	As above

Services: Roads

Table 3–N shows the included reference values for road operations and maintenance. The operations and maintenance of the road network added to the development/settlement within the tool are included in the roads category. Only energy and emissions related to the fuel use of the service vehicles over the distance added to the development is included (this approach omits many important aspects – see section 3.5 for a discussion of limitations). The distance travelled is calculated from the roads added in the web-tool, while the collection frequency and vehicle type (and fuel use) are estimated. The reference values in the web-tool are the frequency of the different categories for summer and winter road service.

Table 3-O. Road service: operations and maintenance

Services: Roads O&M	Value	Unit	Note	Reference / Source
Road cleaning	12	frequency/yr	(1x/month) expert edit ±	
Mowing and trimming	12	frequency/yr	(1x/month) expert edit ±	
Snow removal	13,5	frequency/yr	expert edit ± (old data - winter 2008)	(Giæver and Vaa, 2010)
Spreading sand	13,5	frequency/yr	expert edit ± (old data - winter 2008)	(Giæver and Vaa, 2010)
Salting/Deicing	45	frequency/yr	expert edit ± (old data - winter 2008)	(Giæver and Vaa, 2010)
Snow pole setting	2	frequency/yr	expert edit ± (2x/year for setting and removal)	
Others		frequency/yr	expert edit ±	
Road service fuel use	0,618	l/km cleared road	expert edit ± (data from winter maintenance)	(Vignisdottir et al., 2020, p. 648)

3.4.3. Public costs

The EE Settlement project originally intended to provide some limited, specific cost data in the EE Settlement web-tool. The cost data was expected to be an estimation of the direct public costs to the municipality (or other public agency) that can be attributed to the new development/settlement. Please see section 3.5 for a discussion of issues and limitations.

Included in the EE Settlement web-tool are options for adding the one-time investment costs of building the new non-residential buildings and new infrastructure added in the tool within the new development project or settlement. Also included are options for adding the annual costs arising from road operations and maintenance (O&M), water supply, and wastewater treatment. The standard values in the model are based on information from a variety of private, public, and academic sources but can be adjusted by the user depending on their experiences or expectations. Costs for solid waste collection (which is included in the services section) are not included in the costs section as they are assumed to be fully covered by fees passed directly to the inhabitants/consumers.

The inclusion of this partial cost distribution related to new developments is intended only as an indication of some of the costs that may arise from the new development. This should only be considered an initial overview, and as a supplement to a more thorough economic analysis carried out by the developer, municipality, or other public agency. A more thorough analysis should include many aspects that are absent in this estimation, especially the benefits to society as well as the cost.

A limited set of both operational and investment costs can be estimated in the EE Settlement web-tool. The operational costs which can be added include:

- Road service: operations and maintenance (O&M)
- Water: Freshwater supply & wastewater treatment

The one-time investment costs which can be added include:

- Infrastructure: roads, paths, and associated above and below ground elements
- Non-residential buildings: school buildings, retail, and office

O&M costs: Roads

Operations and maintenance (O&M) costs for roads only include the direct costs to the municipality (or other public agency) for the provision and upkeep of the new roads built as a response to the new development. There are also costs (not included here) for the added maintenance required to existing roads from the driving patterns of the new inhabitants.

A set of "rule of thumb" O&M costs estimates for different road types were obtained from communication with Kristiansand Municipality (KrK, 2021)**.** The values obtained are within the range expected from the specific and average gross operating expenses in the national statistical database for 2020 (SSB 12183, 2021). The operating expenses obtained from Kristiansand Municipality (KrK, 2021), values from a report by the Norwegian Public Roads Administration (Statens vegvesen Vegdirektoratet - SVV) and ViaNova on maintenance costs for walking/cycling paths (Saltnes et al., 2017), and the 2020 "Gross operating expenses in county roads per km (NOK)" from the database of national statistics (SSB 12183, 2021), were used to derive reasonable estimates for average maintenance costs across all road types provided in the tool (Table 3–O).

This mix of sources was used because it allowed a more granular breakdown of costs by road type than could be found within a single data source. As with all generic values provided in the model and web-tool, if the user has or can obtain operating costs more specific to the location of the new settlement – it is recommended for the user to override the default values.

The database of national statistics (SSB 12183, 2021) shows a wide variability in road operating expenses – both between different municipalities, and year to year with within municipalities. The main "municipal" outliers in the 2020 statistics are the large metropolitan regions. Oslo has the highest gross operating expenses for roads, with Bergen, Trondheim, and Tromsø close behind. These four municipalities have expenses that are about 4x higher (per unit length) than the average for the country.

Table 3-P. Reference road costs: operations and maintenance

Costs Roads O&M	Value	Unit	Note	Reference / Source
Sidewalk/bike path (without road)	140	NOK/m/yr	converted from km and updated from cost index	(Saltnes et al., 2017; SSB 08660, 2021)
Urban center road	190	NOK/m/yr	NO average municipal road, 2020 value (updated with est. index of 2%)	(SSB 12183, 2021)
Access road A2	140	NOK/m/yr	KrK estimate	(KrK, 2021)
Access road A1	190	NOK/m/yr	NO average municipal road, 2020 value (updated with est. index of 2%)	(SSB 12183, 2021)
Collector road Sa2	280	NOK/m/yr	KrK estimate	(KrK, 2021)
Collector road Sa1	350	NOK/m/yr	Assumed same as KrK municipal road	(KrK, 2021)
Main municipal road	350	NOK/m/yr	KrK estimate	(KrK, 2021)

O&M costs: Water supply & wastewater treatment

For Norway in 2020, the fee basis per cubic meter of municipal water supply averaged 10,7 NOK/m^3 and the annual fee per cubic meter of water supply averaged about 14 NOK/m^3. The financial coverage rate and self-cost rate were both at about 100%, implying little net national financial impact related to water supply.

Table 3-Q. reference water costs: operations and maintenance

Costs: Water O&M	Value	Unit	Note	Reference / Source
Water supply and wastewater treatment	10,7	NOK/m^3	NO average, 2020 value	(SSB 12218, 2021)

Looking at specific municipalities in 2020, however, there was a very wide range for both the fee basis (from 4,1 to 72,2 NOK/m^3) and the annual fees (from 2,5 to 52 NOK/m^3). While the difference between the fee basis and the annual fees averaged to zero, the range was very large (up to nearly 100 NOK/m^3). It is up to the user to decide whether there is justification for including these water costs in the "direct" costs expected to be covered by the public agency.

Investment costs: Road

Table 3–Q shows the investment costs required per linear meter for construction of each road type. The values shown assume the default configuration in the model/web tool. User edits and customization will change the results. Street lighting and underground networks are included for all vehicular roads. The default separate sidewalk/ bike path includes only lighting and the associated underground power network.

Table 3-R. Reference road costs: investment costs

Investment costs: Roads	Value	Unit	Note	Reference / Source
Sidewalk/bike path	2900	NOK/m	Calculated[4]	(Norconsult and Bygganalyse, 2021)
Urban center road	18900	NOK/m	As above	As above
Access road A2	13100	NOK/m	As above	As above
Access road A1	15100	NOK/m	As above	As above
Collector road Sa2	19000	NOK/m	As above	As above
Collector road Sa1	20100	NOK/m	As above	As above
Municipal road	21500	NOK/m	As above	As above

Investment costs: Non-residential buildings

Table 3–R shows the investment costs required for construction of each non-residential building type. The values shown assume the default configuration in the EE Settlement background model and web tool but can be scaled to match user preferences. User edits and customization will scale linearly based on the costs per square meter. The range of variation which can be tolerated without loss of validity has not been investigated – large deviations from the default configurations should therefore be avoided.

Table 3-S. Reference non-residential building costs: investment costs (detailed)

Investment costs: Non-residential buildings	Value	Unit	Note	Reference / Source
Kindergarten (N-KG)	37600	NOK/m^2	Calculated[4]	(Norconsult and Bygganalyse, 2021)
Primary school (N-PS)	37500	NOK/m^2	As above	As above
Multipurpose sports building/hall (N-SB)	28000	NOK/m^2	As above	As above
Retail building (N-RB)			As above	As above
RB Building	40200	NOK/m^2	As above	As above
RB Cellar	14900	NOK/m^2	As above	As above
Office building (N-OB)			As above	As above
OB Building	23300	NOK/m^2	As above	As above
OB Cellar	14900	NOK/m^2	As above	As above

3.5. Limitations of the building & infrastructure model

This section focusses on the limitations of the background model - limitations specifically related to the methodology, reference values, and data sources. For an overview of general limitations encountered in the EE Settlement project, please refer to the report with guidelines and recommendations: *Bundet energi og klimagassutslipp i nye boligprosjekter. En veileder til beregningsverktøyet EE Settlement* (Barlindhaug et al., 2021).

[4] Values from Prisbok (Norconsult and Bygganalyse, 2021) are not used directly. The line-item costs provided for specific infrastructure and building types are used to custom "build" structures which match the options available in the EE Settlement web-tool. Values presented are rounded to the nearest 100 NOK.

While the user is free to "build" and compare any sort of development or settlement they may be interested in, the ability to derive useful information (and the utility of the comparison) is expected to function best with two specific approaches. These approaches involve the user holding some factors constant while varying others:

1. The same development (plot area, buildings, population, demographics, etc.) placed in two different locations. This allows the user to determine the impact of infrastructure and mobility from the new development (e.g., from an area closer to existing roads and infrastructure and jobs, to one less centrally located).
2. Two different settlements in the same location. In this case it would likely prove most useful to vary only a small subset of factors at a time, to recognize a correlation between changes in inputs and changes in outputs. For example, building types could be changed to compare apartments to single-family houses, while keeping most other factors constant (population housed, distance to centre, etc.).

Comparing two distinct scenarios can also provide useful information for certain stakeholders, and users are not prevented from making these types of comparisons. For example, a city might be interested in quantifying an estimate for the difference in energy use from housing the same population in small centrally located apartments vs. large single-family houses in the suburbs. It should be noted however, that as the number of variables changed increases, the ability to easily draw conclusions about correlations likely decreases. Estimations from the mobility module should be used for comparison purposes only, and not as accurate estimates.

3.5.1. Background data and libraries

The development of the EE Settlement background model involved the collection and reconciliation of a large amount of data from a variety of different sources. These sources have been developed ostensibly to fit the needs of their target users or target sector. These different sectors tend to approach their fields with different needs and with different sets of tools. The result is that the different data sources are difficult to reconcile with each other. This yields a somewhat cumbersome model, with different calculation methodologies applied to different parts of the model. While the buildings are "constructed" from a large materials library, and then assembled into elements which scale according to their application in the building, other parts of the model rely on less granular data and are unable to scale in the same manner. Some of the reference values, especially for services, vary widely from region to region depending on a host of factors. Granular data from which these differences could be teased out were unavailable. Some of the reference values used are drawn from published literature and may be out of date or be poor candidates for geographic extrapolation to a generalized tool for use across Norway.

The materials library is sourced mainly from valid Norwegian EPDs, supplemented with foreign or expired EPDs where necessary, and generic data where no EPDs could be sourced. The authors of EPDs follow standardized procedures from Standards Norway, the European Committee for Standardization (CEN), and the International Organization for Standardization (ISO). The different standards (ISO 14025, 2006; ISO 21930, 2017; NS-EN 15804, 2019) and product category rules (PCRs) (EPD Norge, 2021b; IBU, 2014) allow a large degree of freedom (e.g., decisions regarding which life cycle stages, or "modules" are included), resulting in a large variability of data quality and transparency (Minkov et al., 2015; Waldman et al., 2020).

Building and construction materials are generally calculated using a default reference service life (RSL) of 60 years (NS 3720:2018, 2018). The EE Settlement web tool also uses the 60-year RSL for buildings, though buildings are assumed to remain at the end of the RSL. End-of-life for buildings is not considered in the EE Settlement web tool. Replacement rates for consumable materials (or materials with a shorter RSL than the buildings) are generally included as "modules" within the respective EPDs. To calculate average values from EPDs of materials with equivalent functionality, the "lowest common denominator" of inclusion of life cycle modules would need to be chosen to avoid problems with consistency and reconciliation. To simplify calculations, in cases where discrepancies exist between included modules in EPDs, some EPDs have been excluded. Infrastructure materials often only include modules A1-A4, representing the production phase and (generally) an estimate for A4 (transport to the building site) – in these cases replacement rates were drawn from the literature (Norconsult and Bygganalyse, 2021; SVV, 2018a, 2015) and incorporated into the background calculations.

3.5.2. Public services

As noted above, only direct fuel consumption used by road service vehicles on the new surface infrastructure added in the tool is in included in the calculations. This overlooks many important environmental aspects of road service, which are not covered by this tool. For example, winter road maintenance is important in Norway, and consists of callouts by specialty vehicles for different purposes depending on the situation. These callouts include clearing snow, spreading sand, and spreading de-icing chemicals. A recent life-cycle assessment of Norwegian winter road maintenance found that the "quantity of de-icer used is the main source of emissions contributing toward all impact categories" (Vignisdottir et al 2020, p. 646). There is also a large variation in climate, weather, and corresponding maintenance needs across the length and width of Norway.

3.5.3. Public costs

Attempts to derive simple models for cost calculations is generally complicated by the different revenue approaches that municipalities and other public agencies use to compensate for these costs. For example, some municipalities charge property taxes, while others do not. Some municipalities use tolls, while some do not. The fact that many of the public costs are covered by taxes or fees charged to residents (e.g., water, sewage, and waste taxes, property tax revenues) makes a quick and easy net cost calculation impossible – especially from the point of view of different public agencies. Inclusion of an amortization process, defining a repayment period, and selecting reasonable (and agreed upon) discount rates also complicates the process of quickly or easily allocating costs to the public agencies.

Incorporating cost data with self-cost and income data - with different options for different municipalities or at different levels of government - is not covered by this project. The KOSTRA reporting methodology would seem to provide much of the desired information but is not publicly available at the necessary granularity (SSB, 2021). Likewise, the Norwegian Association of Local and Regional Authorities (KS) and its aggregated management data system (ASSS) system (KS, 2021) appear to have the necessary data, but not publicly available at the granularity needed to derive cost models. A precise and accurate breakdown of demographics would also be required, for example, to calculate costs from kindergartens, primary schools, retirement homes, hospital services, etc. For such purposes, the KOMPAS Municipal planning and analysis system (Cowi, 2021) is likely more suitable.

3.6. References

AIB, 2020. *European Residual Mixes 2019. Results of the calculation of Residual Mixes for the calendar year 2019* (No. Version 1.1, 2020-09-08). association of issuing bodies (AIB), Brussels, BE.

Barlindhaug, R., Kallaos, J., Landa-Mata, I., Engebretsen, Ø., Fjellheim, K., Fufa, S.M., 2021. *Bundet energi og klimagassutslipp i nye boligprosjekter. En veileder til beregningsverktøyet EE Settlement.* (SINTEF Fag 76). EE Settlement Project. SINTEF Academic Press, Oslo, NO.

Bånerud, Ø., Rudén, O., 2013a. *NOTAT: Kostnadsvurdering av boligblokk med kjeller*. Bygganalyse AS, Oslo, NO.

Bånerud, Ø., Rudén, O., 2013b. *Tek07 vs. TEK10. Kostnadsvurdering av boligblokk med kjeller*. Bygganalyse AS, Oslo, NO.

Corgnati, S.P., Fabrizio, E., Filippi, M., Monetti, V., 2013. Reference buildings for cost optimal analysis: Method of definition and application. Applied Energy, Special Issue on Advances in sustainable biofuel production and use - XIX International Symposium on Alcohol Fuels - ISAF 102, 983–993. https://doi.org/10.1016/j.apenergy.2012.06.001

Cowi, 2021. Kompas (Kommunenes plan- og analysesystem)[WWW Document]. Kompas-Forum. URL https://forum.kompas.no/ (accessed 4.4.21).
Deru, M., Field, K., Studer, D., Benne, K., Griffith, B., Torcellini, P., Liu, B., Halverson, M., Winiarski, D., Rosenberg, M., Yazdanian, M., Huang, J., Crawley, D., 2011. *U.S. Department of Energy commercial reference building models of the national building stock* (Technical Report No. TP-5500-46861). National Renewable Energy Laboratory (NREL), US Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE), Golden, CO.
DiBK, 2019. Byggteknisk forskrift (TEK17). Kapittel 5: Grad av utnytting [WWW Document]. URL https://dibk.no/regelverk/byggteknisk-forskrift-tek17/5/innledning/ (accessed 1.13.21).
DiBK, 2017. Veiledning om tekniske krav til byggverk. Byggteknisk forskrift (TEK17) med veiledning. Direktoratet for byggkvalitet (DiBK) National Office of Building Technology and Administration, Oslo, NO.
Dokka, T.H., 2011. *Proposal for CO_2-factor for electricity and outline of a full ZEB-definition* (Memo No. 76). SINTEF Byggforsk, Oslo, NO.
Edelbacher, L., Bußwald, P., Mauerbauer, G., 2021. *User Guide EE Settlement*. EE Settlement Project. akaryon, Vienna, AT.
EPD Norge, 2021a. *EPD-Norge Digi* [WWW Document]. URL https://digi.epd-norge.no/ (accessed 4.5.21).
EPD Norge, 2021b. *Produktkategoriregler* (PCR) [WWW Document]. URL https://www.epd-norge.no/pcr/ (accessed 4.15.21).
EU 244/2012, 2012. *Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements* (Text with EEA relevance). Official Journal of the European Union (OJ) 55, 18–36. https://doi.org/10.3000/19770677.L_2012.081.eng.
Fjellheim, K., Fufa, S.M., 2021. *EE settlement – Norwegian case studies* (SINTEF Notes 39). EE Settlement Project. SINTEF Academic Press, Oslo, NO.
Fufa, S.M., Klinski, M., Azrague, K., Barlindhaug, R., Bußwald, P., Engebretsen, Ø., Finker, C., Landa-Mata, I., Lichtenwöhrer, P., Neugebauer, G., Niederl, F., Stöglehner, G., 2019. *Embodied Energy, Costs and Traffic in Different Settlement Patterns: Background projects and tools* (SINTEF Research 61). EE Settlement Project. SINTEF Academic Press, Oslo, NO.
Fufa, S.M., Kallaos, J., Engebretsen, Ø., Landa-Mata, I., Bußwald, P., Fjellheim, K., Neugebauer, G., Lichtenwöhrer, P., Barlindhaug, R., Felberg, K., Lindjord, J.E., 2021. *EE Settlement final report.* (SINTEF Research 77). EE Settlement Project. SINTEF Academic Press, Oslo, NO.
Giæver, T., Vaa, T., 2010. *Utredning av vinterdriften i Trondheim* (Sintef rapport No. A12786). SINTEF Teknologi og samfunn, Trondheim, NO.
Gloppen, L., Løtveit, B.A., 2018. *Areal- og funksjonsprogram. Båtsfjord 1-10 skole med forsterket avdeling, videregående skole, kulturareal, basishall og helse- og oppveksttjenester.* WSP Norge for Båtsfjord kommune, Trondheim, NO.
Graabak, I., Feilberg, N., 2011. *CO_2 emissions in a different scenarios of electricity generation in Europe* (SINTEF Technical Report No. TR A7058). SINTEF Energy Research.
IBU, 2014. *Product Category Rules for Building-Related Products and Services. Part A: Calculation Rules for the Life Cycle Assessment and Requirements on the Project report* (No. Version 1.3). Institut Bauen und Umwelt e.V. (IBU), Königswinter, DE.
ISO 14025, 2006. *Environmental labels and declarations - Type III environmental declarations - Principles and procedures* (International Standard No. ISO 14025:2006). International Organization for Standardization (ISO), Geneva, CH.
ISO 21930, 2017. *Sustainability in buildings and civil engineering works - Core rules for environmental product declarations of construction products and services* (International

Standard No. ISO 21930:2017). International Organization for Standardization (ISO), Geneva, CH.
Klinski, M., 2018. *EE Settlement: Modelling Task 1.3* (Working Paper No. EE1). EE Settlement Project. SINTEF Community, Oslo, NO.
KrK, 2021. Kristiansand Kommune - personal communication.
KrK, 2015. Veinormal for Kristiansand kommune. Kristiansand Kommune (KrK), Kristiansand, NO.
KS, 2021. KS - kommunesektorens organisasjon [WWW Document]. URL https://www.ks.no/ (accessed 4.4.21).
Landa-Mata, I., Engebretsen, Ø., Barlindhaug, R., 2018. *Embodied Energy, Costs and Traffic in Different Settlement Patterns: Travel behaviour, housing and location preferences* (SINTEF Research 56). EE Settlement Project. SINTEF Academic Press, Oslo, NO.
Larsen, H.N., 2016. *Energianalyse av norsk VA-sektor* (Notat No. c10). Asplan Viak for Norsk Vann, Hamar, NO.
Lausselet, C., Cherubini, F., Oreggioni, G.D., del Alamo Serrano, G., Becidan, M., Hu, X., Rørstad, P.Kr., Strømman, A.H., 2017. *Norwegian Waste-to-Energy: Climate change, circular economy and carbon capture and storage.* Resources, Conservation and Recycling 126, 50–61. https://doi.org/10.1016/j.resconrec.2017.07.025
Løtveit, B.A., Bratholm, E., 2017. *Areal og funksjonsprogram - utkast Haukås skole*. WSP Norge, Trondheim, NO.
Metier, OPAK, LPO, 2013. *Konseptvalgutredning for fremtidig regjeringskvartal*. Metier, OPAK, og LPO arkitekter.
Minkov, N., Schneider, L., Lehmann, A., Finkbeiner, M., 2015. *Type III Environmental Declaration Programmes and harmonization of product category rules: status quo and practical challenges.* Journal of Cleaner Production 94, 235–246. https://doi.org/10.1016/j.jclepro.2015.02.012
NFK, 2017a. Alternativanalyse og tilstandsvurdering vedrørende samlokalisering av Mosjøen videregående skole. Utført for Nordland fylkeskommune (NFK) av OPAK AS og Arkitektskap AS, Oslo, NO.
NFK, 2017b. Alternativanalyse og tilstandsvurdering vedrørende samlokalisering av Narvik videregående skole. Utført for Nordland fylkeskommune (NFK) av OPAK AS og Arkitektskap AS, Oslo, NO.
NIBIO, 2016. Aktuelle lover, forskrifter, normer og veiledninger for dimensjonering av mindre vann-og avløpsanlegg i fritidsbebyggelse. Norsk Institutt for Bioøkonomi (NIBIO).
Norconsult, Bygganalyse, 2021. Norsk prisbok [WWW Document]. URL https://www.norskprisbok.no/Home.aspx (accessed 4.1.21).
NS 3451:2009, 2009. Bygningsdelstabell (Norsk Standard No. NS 3451:2009). Standard Norge (SN), Lysaker, NO.
NS 3457-3:2013, 2013. Klassifikasjon av byggverk - Del 3: Bygningstyper (Norsk Standard No. NS 3457-3:2013). Standard Norge (SN), Lysaker, NO.
NS 3700:2013, 2013. Kriterier for passivhus og lavenergibygninger - Boligbygninger (Norsk Standard No. NS 3700:2013). Standard Norge (SN), Lysaker, NO.
NS 3720:2018, 2018. Metode for klimagassberegninger for bygninger (Norsk Standard No. NS 3720:2018). Standard Norge (SN), Lysaker, NO.
NS 3940:2012, 2012. Areal- og volumberegninger av bygninger (Norsk Standard No. NS 3940:2012). Standard Norge (SN), Lysaker, NO.
NS-EN 15804, 2019. Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products (European Standard No. NS-EN 15804:2012+A2:2019). European Committee for Standardization (CEN) Comité Européen de Normalisation, Brussels, BE.
RVO, 2018. Veileder for Grøftearbeid: Forhold vi bør ta hensyn til ved utførelse av en sikker grøftejobb. Fondet for regionale verneombud (RVO) i bygge- og anleggsbransjen, Oslo, NO.

Saltnes, T.E., Ragnar, E., Granden, M., Holen, Å., Johansen, J.M., 2017. *Kunnskapsoversikt: Drift og vedlikehold for gående og syklende* (Oppdragsrapport). ViaNova Plan og Trafikk for Statens vegvesen Vegdirektoratet (SVV), Sandvika, NO.
Schaefer, A., Ghisi, E., 2016. Method for obtaining reference buildings. Energy and Buildings 128, 660–672. https://doi.org/10.1016/j.enbuild.2016.07.001
SINTEF, 2021. Byggforskserien. Byggforsk.
Siraj, D.K., 2015. Innlegg: Byggekostnadstall uten forståelse blir rot, Bartholdsen [WWW Document]. Bygg.no - Byggeindustrien. URL http://www.bygg.no/article/1243000 (accessed 2.27.19).
Slagstad, H., Brattebø, H., 2014. *Life cycle assessment of the water and wastewater system in Trondheim, Norway – A case study*. Urban Water Journal 11, 323–334. https://doi.org/10.1080/1573062X.2013.795232
SSB, 2021. KOSTRA - Kommune-Stat-Rapportering [WWW Document]. URL https://www.ssb.no/offentlig-sektor/kostra/ (accessed 4.4.21).
SSB 04936, 2021. Municipal water supply. Table 04936: I. Water - key figures (M) (closed series) 1999 - 2016 [WWW Document]. URL https://www.ssb.no/en/statbank/table/04936 (accessed 4.6.21).
SSB 07459, 2021. Population. Table 07459: Population, by sex and one-year age groups (M) 1986 - 2021 [WWW Document]. URL https://www.ssb.no/en/statbank/table/07459/ (accessed 3.21.21).
SSB 08660, 2021. Construction cost index for road construction. Table 08660: Cost index for maintenance of roads (1st quarter 2004=100) 2000 - 2020 [WWW Document]. URL https://www.ssb.no/en/statbank/table/08660/ (accessed 2.12.21).
SSB 11787, 2021. Municipal water supply. Table 11787: Water supply and safety and preparedness plans (M) 2015 - 2020 [WWW Document]. URL https://www.ssb.no/en/statbank/table/11787 (accessed 3.20.21).
SSB 12183, 2021. Table 12183: Economy within transport (M) 2015 - 2020 [WWW Document]. URL https://www.ssb.no/en/statbank/table/12183/ (accessed 3.17.21).
SSB 12218, 2021. Table 12218: Self cost and fees in municipal water supply, by contents, region and year. Statbank Norway [WWW Document]. URL https://www.ssb.no/en/statbank/table/12218/tableViewLayout1/ (accessed 3.7.21).
SSB 13136, 2021. Table 13136: Household waste, by material, treatment and downstream system (M) 2015 - 2020 [WWW Document]. URL https://www.ssb.no/en/statbank/table/13136/ (accessed 3.21.21).
SVV, 2021. Vegkart [WWW Document]. URL https://vegkart.atlas.vegvesen.no/ (accessed 4.3.21).
SVV, 2019. Veg- og gateutforming (Håndbøk - Normal No. N100), Statens vegvesens håndbokserie. Statens vegvesen Vegdirektoratet (SVV), Trondheim, NO.
SVV, 2018a. Vegbygging (Håndbøk - Normal No. N200), Statens vegvesens håndbokserie. Statens vegvesen Vegdirektoratet (SVV), Trondheim, NO.
SVV, 2018b. Rutiner for graving og legging av ledninger over, under og langs offentlig veg. Statens vegvesen Vegdirektoratet (SVV), Trondheim, NO.
SVV, 2016. Lærebok Vegteknologi (Rapport No. 626), Statens vegvesens rapporter. Statens vegvesen Vegdirektoratet (SVV), Trondheim, NO.
SVV, 2015. Utførelsens betydning for asfaltdekkers levetid (Rapporter No. 392), Statens vegvesens rapporter. Statens vegvesen Vegdirektoratet (SVV), Trondheim, NO.
SVV, 2014a. Sykkelhåndboka (Håndbøk - Veiledning No. V122), Statens vegvesens håndbokserie. Statens vegvesen Vegdirektoratet (SVV), Trondheim, NO.
SVV, 2014b. Teknisk planlegging av veg- og tunnelbelysning (Håndbøk - Veiledning No. V124), Statens vegvesens håndbokserie. Statens vegvesen Vegdirektoratet (SVV), Trondheim, NO.
SVV, 2014c. Energibesparende vegbelysning (Rapport No. 646), Statens vegvesens rapporter. Statens vegvesen Vegdirektoratet (SVV), Oslo, NO.
SVV, 2014d. Veg- og gateutforming (Håndbøk No. N100), Statens vegvesens håndbokserie. Statens vegvesen Vegdirektoratet (SVV), Trondheim, NO.

TK, 2015. Funksjons- og arealprogram for kommunale skoleanlegg i Trondheim. Trondheim Kommune (TK), Trondheim, NO.
TK, 2014. Funksjons- og arealprogram for kommunale barnehageanlegg i Trondheim. Trondheim Kommune (TK), Trondheim, NO.
VA-Miljø, 2021. Miljø-Blad [WWW Document]. URL https://www.va-blad.no/ (accessed 3.26.21).
VA-Norm, 2019. VA-Norm Kristiansand [WWW Document]. URL http://www.va-norm.no/kristiansand/ (accessed 11.18.19).
VBT, 2015. Veileder: Ledninger i kommunale veger. Vegforum for byer og tettsteder (VBT).
Venås, C., Mellegård, S., 2018. *Beregningsverktøy for bærekraftig by- og regionsutvikling: Identifisering av behov – workshop og intervjuer* (SINTEF Notat 32). EE Settlement Project. SINTEF Academic Press, Oslo, NO.
Venkatesh, G., 2011. Systems performance analysis of Oslo’s water and wastewater system (PhD). Norwegian University of Science and Technology (NTNU), Trondheim, NO.
Venkatesh, G., Brattebø, H., 2011. Energy consumption, costs and environmental impacts for urban water cycle services: Case study of Oslo (Norway). Energy 36, 792–800. https://doi.org/10.1016/j.energy.2010.12.040
Vignisdottir, H.R., Ebrahimi, B., Booto, G.K., O’Born, R., Brattebø, H., Wallbaum, H., Bohne, R.A., 2020. *Life cycle assessment of winter road maintenance*. The International Journal of Life Cycle Assessment 25, 646–661. https://doi.org/10.1007/s11367-019-01682-y
Waldman, B., Huang, M., Simonen, K., 2020. Embodied carbon in construction materials: a framework for quantifying data quality in EPDs. Buildings and Cities 1, 625–636. https://doi.org/10.5334/bc.31

4. Mobility simulation (Norway)

The mobility simulation tool (MST) is an integrated module in the EE-model and estimates the following:

- transport mode choice probabilities of residents for journeys starting in the planned residential settlement,
- daily car vehicle kilometres (vkm) ‘generated’ by residents – including trip chains (as drivers) linked to the planned settlement (not including long distance travel and driving outside the region),
- energy consumption and emissions associated to the latter (car vkm).

Estimations for mode choice probabilities and car vkm are based on values retrieved from the settlement’s characteristics previously entered in the tool (e.g., share of people residing in apartments) and on additional values on socio-economic and contextual characteristics of the settlement provided by the user (e.g., availability and frequency of public transport in the area). The estimation of some values is facilitated by coupling the online tool to (geo)data from Statistics Norway via an API (e.g., local population density) and by suggesting relevant main regional centres. If the user fails to provide any of these values, default values are provided by the tool.

Default values and model parameters to estimate the output variables are based on previous regression analysis run on geo-located registry data and data from the Norwegian National Travel Survey (NTS) 2013/14. Values are entered in five regression models that run in the background: four logistic models for estimating mode choice probabilities (car driver, car driver and passenger, public transport, and non-motorized transport) and one linear regression model for estimating car vkm.

The selection of variables to include in these models is grounded on existing literature on factors explaining travel behaviour and are briefly reviewed in section 4.1. However, compromises needed to be made to balance what – according to previous studies – are relevant explanatory variables, on one hand, and existing available data in Norway, as well as its usability, not least from a user’s perspective, on the other hand. In section 4.2, we review the final choice of variables and their operationalization, i.e., the selection of indicators to measure these variables and the preparation of data to feed in the models and estimate parameters. Section 4.2 also describes regression analyses made, as well as how the MST estimates energy consumption and emissions associated to the estimated car vkm generated by residents for trip chains starting in the settlement.

The MST’s limitations are discussed at the end of this chapter in section (4.3). Consideration of these limitations and testing of results indicates that the MST is useful to make comparisons but not to provide accurate figures on any of the estimated outputs.

The MST builds upon and further develops previous models and methods based on NTS for estimating the number of car trips to and from residential areas (Hanssen & Engebretsen 2006), estimating transport impacts of alternative regional development plans (Strand et al. 2013), and estimating vkm (Engebretsen 2018).

4.1. Theoretical background

Indicators mainly used to evaluate travel behaviour are trip frequency, modal shares, travelled distances and travel time. How and how much individuals travel, along with the powertrain of the vehicle, influence the scope of energy consumption and carbon emissions. Thus, modal shares (particularly car shares) and travelled distances are the key variables of interest needed to estimate the energy needs associated to travel generated by the settlement's residents, which is the aim of MST module integrated in the EE-model, as well as one of the project's goals.

A review of tools used in Norway for transport planning concludes that existing tools would demand a considerable amount of resources and knowledge from municipal developers and planners and yet not be detailed and flexible enough to estimate the transport related energy generated by dwellers of new residential settlements (Fufa and Klinski et al., 2019). The same report highlights the higher flexibility of guidelines to calculate trip generation, but also their limits regarding comparability across cases. We therefore chose to develop a new model that can be applied at different cases and is easy to use.

The identification of explanatory variables to be included in the model mainly builds on a review of international studies published in/after 2000, which was conducted between November 2017 and January 2018 by project members (Landa-Mata, Engebretsen, Barlindhaug, 2018). According to this review, factors that significantly influence travel model choices and distances travelled can be grouped into contextual, socio-economic/demographic and attitudes/preferences dimensions. The following summary is based on findings published in that report and limited to review variables that affect car use and car vkm, as these are key indicators to estimate transport-related energy needs generated by dwellers of residential settlements. For a more thorough review, e.g., how the effects of these variables may be mediated by travel purpose, likelihood of choosing other transport modes and a description of the literature review process itself, please consult the report (Landa-Mata et al., 2018).

Given the project's goal, the influence of **contextual** characteristics of the settlement on travel behaviour are of particular interest. Studies indicate that residential location, local densities, land use, parking availability and public transport standards and – to a lesser extent – dwelling types affect travel behaviour. Here we briefly review these factors. We do not include further factors at a local (e.g., street design) and regional scale (regional connectivity) that may affect travel behaviour.

Location of the settlement is a key variable to be considered, as studies show that *distance to the regional main city centre* (and to a lesser extent to second-order centres) has a positive effect on car use and vkm. The farther the residence is located from the centre, the higher the likelihood of choosing the car and the higher the distance travelled. Some studies indicate that this effect may be a reflection of the effect of local contextual characteristics, as residential areas closer to the city centre tend to be denser built and populated and to be better served by public transport and further services. Also, car ownership may be at play here, as individuals residing in outskirts tend to have better access to car(s). It is, thus, important to also account for such local contextual and socio-economic characteristics in the analysis.

Among the local contextual characteristics that studies find influential for how individuals choose to travel in journeys starting at home, we find *population, jobs, and services densities* in the residential area. Dense urban areas usually exhibit good availability of services, including grocery shops and public transport services within walking distance. This facilitates walking and choosing public transport to fulfil different purposes and cover needs that demand travel. Conversely, sparsely populated areas are characterized by poor public transport services and long distance to shops and further services. This increases the probability of using the car. Studies have also found a negative effect of density at larger scales (e.g., urban area) on car use. A further and related influential factor pertaining the residential area is *land-use mix*. Although there are relatively fewer studies including this variable in the analysis, they indicate that functional mix-use measured as e.g., the availability of a range of services, the number of jobs or the ratio of jobs to residents in the residential area has a negative effect on car use and vkm, as daily needs and purposes can be fulfilled within walking and cycling distances.

A further influential factor according to the literature reviewed is *workplace location* in relation to the dwelling and urban centre. Such distances and associated local contextual characteristics (e.g., local densities, parking availability, public transport services) contribute to explain how individuals choose to commute. Moreover, it can affect daily travel behaviour because travel related to other purposes can be concatenated with trips to/from work in trip chains.

Studies also show that *parking availability* at both place of residence and destination (e.g., workplace) also affect how individuals choose to travel. Having parking lot(s) available at or close to home increases the likelihood of using a car. The same applies to free parking availability at the workplace. Contrarily, having to walk to the car parking space and/or to pay for it, reduces the likelihood of using the car. In a similar way, *public transport standards* – measured either as distance to public transport stations/stops, frequency and/or quality of services – also affect travel mode choice. Short distances to stations/stops, higher frequencies and better services increase the likelihood of choosing public transport and, thus, reduce car use.

There are few studies investigating the influence of *dwelling type* on travel behaviour, but they indicate that individuals living in apartment blocks tend to use the car less, than individuals living in semi-detached and detached housing. However, it is important to note that these effects can be also explained by characteristics associated to those dwellings (e.g., detached houses tend to have ample parking spaces and be located in less dense areas) and individuals/households (e.g., people living in detached houses tend to have higher incomes and higher material standard lifestyles).

Most studies investigating the effect of urban structure and the built environment on travel behaviour also include **socio-economic and demographic** variables in their analyses to control for their effects on the variables of interest. Not accounting for these variables could led attributing their effects to other variables. For instance, some of the positive effect of residing in an area far from the urban centre on the likelihood to drive a car could be explained by having access to several cars and/or by the presence of children in the household, which in turn may have influenced the decision to settle down at this particular location (given that it is difficult and costly to find spacious dwellings in areas closer to the urban centre).

Holding a driving license, having access to car (whether this is operationalized either as 'car ownership' or 'numbers of cars in the household'), *income* and the presence of *children in the household* increase the likelihood of travelling by car and car vkm, whereas having a high *education* reduces the likelihood to choose the car as travel mode (but has a positive effect on car vkm too). When it comes to income, it is important to note that not all studies reviewed in the report found significant effects of this variable on car use and that such effect seems to depend on contextual characteristics and/or which other control variables are included in the analyses. Moreover, the effect of income on car use may change once a certain threshold is reached. Income is correlated with education and occupation and may, thus, capture some of the effect which may actually be attributed to these variables, since the latter are usually included in studies to a lesser extent. In a similar vein, some of the negative effect of education on car use may be actually explained by contextual factors, at least in the Scandinavian region, where jobs requiring high education tend to be located in areas well-served by public transport.

Studies also indicate that *gender, age,* and *occupation* contribute to explain travel mode choices and vkm, although findings on their effects seem to be more mixed. While some studies indicate that being a female reduces the likelihood to drive a car, this effect seems to disappear when employment situation and the household composition (number of children in the household) are considered. Also, although being employed increases the likelihood to use the car, certain occupations may reduce such likelihood. Yet, again, in such cases this effect may be explained by contextual factors, as it happens in the case of education. The literature reviewed also indicates that the sign of the relationship between age and car vkm varies across areas investigated, and that the effect of age on travel mode choice varies depending on which other control variables are included in the analyses (e.g., public transport quality, parking availability). Despite these relationships being less clear, it seems relevant to include all these variables in a model that aims to estimate car use associated to the development of a residential settlement.

Considerably fewer studies include **attitudes and preferences** into regression analyses, but those which do so find that *attitudes and preferences towards the car and other transport modes* (e.g., car-dependent, pro-bike/walk, pro-transit), as well as *perceptions about the transport mode attributes* (e.g., travel time, accessibility, reliability, comfort, safety) affect travel mode choice and travelled distances. Also, *residential preferences* seem influential for car ownership (which, as we have described, affects car choice) and how much (vkm) people travel.

4.2. Method for estimating transport related energy consumption and emissions

Model parameters were calculated using multivariate regression analyses conducted on geo-located survey-based travel data from Norway coupled with registry data and map data (GIS) measuring output and explanatory variables reviewed above.

Data sources employed in this analysis were the Norwegian National Travel Survey (NTS) 2013/14 (TØI) for data on individual daily travel and socio-economic and demographic characteristics, the Norwegian Mapping Authority’s Cadastre and Land Registry for data on housing stock, Statistics Norway for grid data on population and workplaces, the Business and Enterprise register for data on business and employment in sectors with central functions (Statistics Norway and TØI), map data and statistics on urban areas and centre zones (Statistics Norway), Entur for open data on public transport (Entur AS) and TØI’s distance matrices between basic statistical units[5] (based on ArcGIS Network Analyst applied to data from Elveg - electronic road network - Norwegian Mapping Authority).

The estimation of car vkm is, thus, a function of a set of variables that – according to the literature and our regression analyses – explain distances travelled by car. These and additional explanatory variables are used to estimate car choice (as driver) and further modal share probabilities: car (both as driver and passenger), public transport and bike/walk.

The estimation of transport related energy consumption and emissions is a function of car vkm and their distribution by vehicle power train. For this, we used estimations made by Fridstrøm (2019). Figure 4–1 illustrates the mobility model behind the MST.

[5] Basic statistical units (grunnkretser) are subdivisions of municipalities, used by Statistics Norway to provide stable and coherent geographical units for regional statistics. There are approximately 14.000 basic statistical units in Norway, most of which include only a few hundred inhabitants. In cities, units have only a small geographical extent.

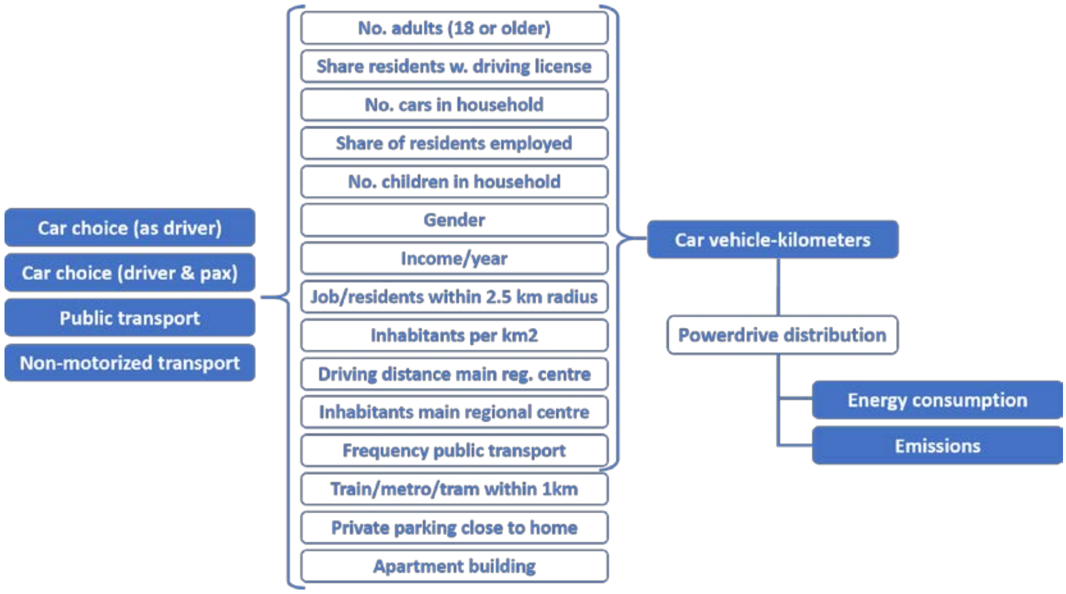


Figure 4–1. Mobility model behind the MST

As illustrated in the figure, modal share estimations are not used in the calculation of transport related energy consumption and emissions, as vkm are estimated in a one-step function and not as a two-step function (car choice → vkm).

MST does neither include vkm, energy consumption and emissions related to visitors' driving and home deliveries nor goods transport and traffic to businesses, shops, schools, kindergartens etc located in the area[6]. Furthermore, vkm, energy consumption and emissions associated with the residents' travelling by public transport[7] and as car passengers[8] is not included.

4.2.1. Operationalization of explanatory and output variables

The selection of indicators to be included in the regression models and the MST is based on variables i) deemed relevant by previous studies for explaining travel mode choices and vkm; and ii) with significant independent contributions to the models' explanatory power; as well as on iii) data availability for the regression analysis and iv) how easy it will be to retrieve data on the indicator for the user of the EE-model. That is why the MST does not comprise all explanatory variables reviewed in section 4.1.

During the process of developing a model, several indicators on selected explanatory variables were tested. Some were changed or disregarded either because regression analyses suggested they had non-significant effects on output variables and/or because it was practically difficult (particularly for users) to retrieve data on them. In addition, many indicators were correlated with each other and may cause multicollinearity in the models. The number of variables included in the analyses was therefore reduced to those that make significant independent contributions to the models' explanatory power. In the following we review operationalization of selected variables to come up with model parameters and used in the online MST.

In the regression models and in the calculations built into the MST, transformed values are used for some of the indicators (due to non-linear relationships or the need for rescaling). However,

---

[6] Previous studies (Hanssen & Engebretsen 2006) have estimated visitors' car trips (including those related to home delivery etc) to be about 15-20 percent of the number of all car trips to and from private homes. However, it is not straightforward to estimate vkm based on such shares, as this would demand identifying the portion of driving related only to the visit to the settlement.
[7] Such estimations had to focus on the effects of increased capacity, new lines etc. – if existing service is not sufficient. It will be demanding to obtain such information and in addition unnecessary since the prevailing policy is to transfer traffic from car use to public transport.
[8] Would have implied double counting of the settlements vkm, energy use and emissions.

users of the online MST are only asked to enter untransformed values (the MST performs the transformations automatically).

Residential location. Studies generally operationalize this variable by choosing indicators that measure the distance from home/work addresses to the primary city centre (central business district – CBD) and, sometimes, to second- and third-order centres. However, in contrast to studies that investigate travel behaviour in a given metropolitan area and/or region, our regression models used travel data at national level. This posed a significant challenge: finding the 'urban centre' for all individuals' home addresses contained in the NTS dataset. We did this by locating the largest central area (in terms of employment in sectors with central functions[9]) within 45 minutes driving time (given by the speed limit) and a minimum share of commuting at the municipal level[10]. To do so, we used the Business and Enterprise Registry[11] (2018), Statistics Norway's definition on central zones, statistics of commuting (Statistics Norway), and a dataset developed by TØI containing travel distances between all basic statistical units in Norway. In practice, central zones correspond to the CBD in the primary city of the region. The independent variable for the regression models is the distance from the home address (in NTS) to the actual central zone. The relationship is not linear; therefore, the logarithm value of the distance is used in the models.

In addition to the distance to the city centre, a variable of the **degree of urbanization** in the region is also included - measured as the size of the primary city (number of residents).

For the MST, it should in principle be obvious which is the main regional centre (primary city) in the region. Nevertheless, once a new settlement has been located by the user, the MST automatically suggests five regional centres which are closest to the settlement[12]. By selecting one of the alternatives, the online MST automatically retrieves '*regional centre's population size*'. The user can also select the suggested '*distance from the settlement to the regional centre*'. Alternatively, the user can input another distance.

Local density is measured by the number of '*inhabitants per km^2 of built-up areas within 1000 m of the settlement*'. For the regression models this indicator is calculated using grid cells (250 m x 250 m) data from Statistics Norway on population. To estimate the model's parameters, the number of residents in all grid cells within 1000 meters from the survey-based home addresses' is divided by the area of each cell (within the same radius) that contains residential or commercial buildings. The relationship is not linear; therefore, the square root of the local density is used in the models. Ideally, the MST should use land use densities as indicator. However, such data is demanding to obtain, whereas grid data is updated every year and can be downloaded from Statistics Norway's website.

The online MST retrieves grid data from Statistics Norway via an API and calculates the indicator after having added the number of residents in the new settlement to the existing population in the area.

As an expression of **regional dependency**, an indicator is used that measures the local coverage of jobs. High regional dependency (low value of the indicator) can be assumed to affect the need for interaction outside the local area and thus have impact on travel behaviour, which is

---

[9] For a definition of sectors with central functions please refer to SSBs definition available at https://www.ssb.no/en/natur-og-miljo/statistikker/arealsentrum. We did not count sole proprietorship companies with 1 or less employees We also considered to focus the selection to sectors belonging 'trade and service zones' but chose sectors with central functions because they cover a wider range of services.
[10] The distance and commuting requirements have been adjusted in sparsely populated areas, and in some areas in large municipalities that are divided into several commuting areas.
[11] TØI prepares each year a modified and expanded version of the Central Business and Enterprise Register (VoF). The register constitutes Statistics Norway's reference population for all economic activity in Norway. The local activity units are the smallest units about which statistics are collected and are unequivocal with regard to industry and geography (as opposed to enterprises).
[12] This is based on straight distances (as the crow flies) using data freely available. Given Norway's topography, the user will need to evaluate which is the closest regional centre along the road network.

indicated in previous studies (Engebretsen and Christiansen 2011). For the regression models the indicator expresses the '*ratio between the number of full-time jobs and the number of inhabitants within 2,75 km radius from the settlement*'. To estimate the model's parameters, this proportion was calculated using data from Statistics Norway's 250 m x 250 m grid cell data on jobs and population in all grid cells within a 2,75 km radius from the survey-based home addresses (the distance is measured to the midpoints of the grid cells). The online MST retrieves this data via an API – and calculates the ratio after having added the number of residents in the new settlement to the existing population in that area. No changes are made to the number of workplaces in that area, i.e., it is assumed the development of the new settlement will not change this.

Parking availability is for the regression models measured based on data from the NTS 2013/14. Respondents were asked whether they have private parking close to home and given three options to answer: 'yes', 'no' and 'I don't know'. The variable has been dichotomized (1=no; 0=yes) to conduct the regression analysis.

In the online MST, the variable is inversed so that users are requested to input the '*share of residents (in the new settlement) with access to private parking close to home*'.

Public transport standard is operationalized in the regression models using two indicators: 'average number of departures per hour from the closest public transport stop(s) (regardless type of public transport) during peak hour time (between 7:00 and 08:59)' and 'access to a train, metro or tram station within 1 km from the settlement'. To estimate the model's parameters, ENTUR geo-located data[13] was coupled to survey-based home addresses' coordinates. The relationship is not linear; therefore, the square root of departures is used in the models. The maximum average number of departures is additionally set up at 30.

The online MST is not coupled to ENTUR data and users are requested to input these values based on their knowledge. In terms of access to train, metro or tram, the input to the tool is the proportion of new residents within the catchment area of the station/stop (1 km).

Type of dwellings in the regression model is a distinction between living in an apartment block or not (binary variable)[14]. To estimate this parameter, we coupled survey-based home addresses' coordinates to the Norwegian Mapping Authority's Cadastre and Land Registry, which contains geo-located data on all buildings by building type.

In the online MST the corresponding indicator is '*share of residents living in apartment blocks in the new settlement*'. The value of the indicator is automatically retrieved based on the number of residents living in different types of buildings comprising the settlement.

Having access to car is operationalized in the regression models using data from the NTS 2013/14, in which respondents were asked how many cars their household owns or dispose.

In the online MST, users are requested to estimate the '*average number of cars per household in the new settlement*'.

Personal income is in the regression models based on self-reported data from the NTS 2013/14. The value is transformed to the square root of income measured in 100.000 NOK per year.

In the online MST, users are requested to estimate the '*average personal income per year*' among residents of the new settlement.

Household characteristics is operationalized based on data from the NTS 2013/14 to estimate the regression models' parameters. We use both the '*number of children in the household (up to 17 years old)*' and the '*number of residents aged 18 and older*'. Both indicators are based on

[13] It is possible instead, to use self-reported data on public transport frequencies. Effects' size and significance were similar to those of using geo-located ENTUR data. The latter was however preferred because it is more similar to the type of information users of the tool will most likely have access to.
[14] We also tested the effect of living in other types of buildings (detached, semi-detached houses), but we found coefficients were only significant for apartment blocks.

respondents’ response on questions regarding how many people live in the household and their age.

The online MST automatically retrieves the value on these indicators based on the demographic information of the new settlement.

Gender is for the regression models measured based on data from the NTS 2013/14 (dichotomous indicator). In the online MST, users are requested to estimate percentage of women in the new settlement.

Economically active population is operationalized in the regression models by using a dichotomous indicator based on data from the NTS 2013/14. The indicator builds on respondents’ answers on whether they are employed.

In the online MST, users are requested to estimate the share of employed persons among residents over 18 years of age in the new settlement.

As described, the online MST automatically retrieves the share of residents living in apartments as well as the number of children and adults per household from other modules in the EE-model. For indicators on local density, regional dependency, relative location, and degree of urbanization the MST makes suggestions based on the location of the settlement, that the user may or not accept. For all the other explanatory variables, the main idea is that the user shall fill in own information (values). If the user fails to provide own values for the settlement, the MST automatically will retrieve default values. Default values are based on national averages based on weighted survey-based data from the NTS 2013/14. For certain indicators local values will substantially differ from national default averages, especially for indicators related to the settlement’s location and the settlement’s design. It is therefore recommended to fill in local values for as many indicators as possible (except for those retrieved from other modules).

Table 4–A provides an overview of indicators used in the model and MST to operationalize relevant explanatory variables along with their definition and sources.

Table 4-A. Overview of indicators included in MST

Variable	Indicator	Definition	Data used in MST	Data used in regression models for estimation of MST's parameters
Type of dwelling	Apartment building (share of residents) (*)	Share of residents living in apartment buildings in the new settlement	Settlement design	Norwegian Mapping Authority's Cadastre and Land Registry
Local density	Inhabitants per km^2 of built-up areas within 1000 m.	Population density (inhabitants per km^2 of built-up areas) within a radius of approximately 1 km (as the crow flies) from the settlement	Grid cells (250x250m) data on population, Statistics Norway, via API	Grid cells (250x250m) data on population, Statistics Norway
Public transport standard	Frequency public transport (no. departures from closest stop(s) in morning peak hour)	Average number of departures per hour from the closest public transport stop(s) (regardless type of public transport) during peak hour time (between 7:00 and 08:59). Maximum value = 30	Users' estimations/knowledge	ENTUR data
Public transport standard	Train/metro/tram within 1 km (*)	Share of residents with access to a train, metro, or tram station within 1 km from the settlement (0=none;1=all)	Users' estimations/knowledge	ENTUR data
Private parking	Private parking close to home (share of residents) (*)	Share of residents in the new settlement with access to private parking	Users' estimations/knowledge?	NTS 2013/14
Residential location	Driving distance (km) to the main regional centre from dwelling (if 0-1 km set to 1)	Driving distance (km) between the settlement and the city centre of main regional centre (if the settlement is located in the regional main centre, insert 1)	Retrieves upon users' selection among five main regional centres suggested	Business and Enterprise Registry, TOIs distance matrix
Regional dependency	Jobs/residents within 2,75 km radius	Proportion between number of full-time jobs and the number of inhabitants within 2,75 kilometre radius from the settlement	Grid cells (250x250m) data on jobs and population, Statistics Norway, via API	Statistical basic unit's data on jobs and population, Statistics Norway and Business and Enterprise Registry
Degree of urbanization	Inhabitants main regional centre	Number of inhabitants in the main regional centre	Retrieves upon users' selection among five main regional centres suggested	Statistics Norway

Personal income	Income / year	Average income per year (personal mean value - not household) among residents of the new settlement	Users' estimations/knowledge	NTS 2013/14
Gender	Gender (share of female population)	Average share of female population among residents of the new settlement	Users' estimations/knowledge	NTS 2013/14
Household characteristics	No. children in the household	Average number of children in the household (up to 17 years old) in the new settlement	Settlement design	NTS 2013/14
Economically active population	Share of residents employed	Average share of population employed (i.e., income generating job as main activity) in the new settlement	Users' estimations/knowledge	NTS 2013/14
Car ownership	No. cars in the household	Average number of cars per household in the new settlement	Users' estimations/knowledge	NTS 2013/14
Driving license	Share of residents with driving license	Average share of residents in the new settlement (among people aged 17 and older) holding a driving license	Users' estimations/knowledge	NTS 2013/14
Household characteristics	Number of persons >= 18 years	Number of residents aged 18 and older in the new settlement	Settlement design	NTS 2013/14

(*) only included in logistic regression models estimating transport mode choice probabilities, not in model estimating vkm.

4.2.2. Deriving parameters for mode choice and vkm estimation

To estimate parameters for MST, we have used survey-based data from the NTS 2013/14 as the regression models' dependent variables – **mode choice** and **vkm**. Mode choice is based on respondents selected main transport mode in trip chains starting at home. Vkm is based on a combination of model-calculated and survey-based self-reported distances as car driver on the included trip chains. Model-calculated distances are from TØI's distance matrices between basic statistical units (based on ArcGIS Network Analyst applied to data from Elveg - electronic road network - Norwegian Mapping Authority).

Table 4–B shows the results of the logistic regression models estimating the probability of traveling as a driver (model 1), traveling by car (as driver or passenger – model 2), using public transport (model 3), or walking or cycling (model 4). The estimates apply to trip chains that start at home. Most of the independent indicators (explanatory variables) have significant effect at one percent level or lower (for model 1 and model 2, this applies to all variables)[15]. In model 1 and model 2 indicators with negative regression coefficient (B1 and B2) reduce the probability of using the car, whereas the other indicators increase such probability. Naturally, in model 3 and model 4 most regression coefficients have opposite signs compared to model 1 and model 2.

Table 4-B. Probability of traveling as driver, traveling by car (as driver or passenger), traveling by public transport, or walking or cycling. Trip chains starting from home. NTS 2013/14. N=76 630.

	Model 1 – driver			Model 2 – car use			Model 3 – pub. transport			Model 4 – non-motorized		
	B1	Wald1	Exp(B1)	B2	Wald2	Exp(B2)	B3	Wald3	Exp(B3)	B4	Wald4	Exp(B4)
Apartment building etc	-0,244***	96,5	0,784	-0,256***	111,5	0,774	0,084**	4,4	1,088	0,168***	48,1	1,183
SQRT Inh.(1000)/km^2 built-up areas within 1 km	-0,241***	100,8	0,786	-0,218***	84,5	0,804	0,214***	36,7	1,238	0,072***	10,0	1,074
SQRT Public transp. freq 07:00-09:00	-0,039***	19,2	0,962	-0,035***	16,1	0,965	0,096***	43,2	1,101	0,043***	24,1	1,044
Train/metro/tram within 1 km	-0,205***	73,0	0,815	-0,216***	83,1	0,806	0,298***	53,4	1,347	0,124***	25,9	1,132
Lacks own parking space close to home	-0,543***	139,2	0,581	-0,536***	155,9	0,585	0,238***	24,1	1,269	0,07*	3,6	1,073
Ln(km) to main regional centre	0,102***	89,9	1,108	0,138***	163,5	1,148	0,0999***	19,3	1,105	-0,176***	260,4	0,839
Jobs per resident within 5 min driving	-0,224***	57,3	0,799	-0,179***	36,6	0,836	-0,248***	21,1	0,781	0,214***	51,8	1,238
Inhabitants main regional centre (1000)	-0,0002***	23,1	1,000	-0,0003***	64,3	1,000	0,001***	334,3	1,001	-0,0001***	14,1	1,000
SQRT(Income) (NOK 100,000 / year)	0,081***	29,6	1,084	0,047***	10,1	1,048	-0,232***	83,6	0,793	0,025*	2,8	1,025
Woman	-0,538***	939,8	0,584	-0,254***	210,6	0,776	0,206***	45,1	1,228	0,236***	180,6	1,267
Number of children in the household	0,133***	206,0	1,142	0,095***	103,8	1,100	-0,14***	57,1	0,870	-0,056***	33,9	0,946
Employed	0,174***	69,0	1,191	0,118***	32,0	1,125	0,344***	86,5	1,411	-0,262***	159,4	0,769
Number of cars in the household	0,421***	1043,2	1,523	0,436***	1101,8	1,547	-0,573***	535,3	0,564	-0,291***	489,4	0,747
Driver's license (dichotomy)	3,128***	1721,4	22,819	1,569***	1581,0	4,801	-0,996***	588,9	0,369	-0,586***	344,7	0,557
Number of persons >= 18 years	-0,149***	137,5	0,862	-0,083***	44,6	0,920	0,204***	115,2	1,227	-0,006	0,2	0,994
Constant	-2,653***	855,3	0,070	-1,113***	303,1	0,329	-2,451***	563,1	0,086	0,093	2,5	1,097
Nagelkerke R2	0,27			0,23			0,21			0,10		
* p<0.10, ** p<0.05, *** p<0.01												

The regression coefficients $B1_1$, $B1_2$, $B1_3$, …. $B1_{15}$ and C (constant) in Table 4–B can be used in a formula for estimating the probability of traveling as a driver (P(driver)):

$$P(driver) = \frac{1}{\left(1 + e^{-(\sum_{i=1-15} B1_i \cdot X_i + C)}\right)}. \qquad (1)$$

X_1, X_2, X_3, …. X_{15} represents the independent indicators (explanatory variables) in the first column in the table.

[15] In the model, there are no indications of multicollinearity and no problematic correlations between the explanatory variables - with one exception. The correlation coefficient between density and public transport frequency is more than 0,7. However, since both have a significant effect and expected sign and it does not cause multicollinearity, we have chosen to include both variables.

The formula (1) and the coefficients $B1_1$, $B1_2$, $B1_3$, …. $B1_{15}$ as well as mean values of untransformed indicators (the MST automatically transforms the indicators) are implemented in the MST. The MST estimates P(driver) based on indicators from other modules in the EE-model, values added by the user or the default values.

As for the results from the model 1, coefficients (B2, B3 and B4) and formulas (like (1)) based on models 2, 3 and 4 are implemented in the MST.

Model 1 only explains about a quarter of the variation of the dependent variable (being a car driver)[16]. For model 2 and model 3, the degree of explanation is slightly lower, while for model 4 it is significantly lower. To increase the precision of the models, it is necessary to include information about trip purposes, contextual properties related to the destinations, and accessibility levels in the transport network. With such information, the degree of explanation can be raised to 50 percent or more for the models 1-3. For the MST, however, such information is not available. On the other hand, a test with a somewhat extended version of model 1 (with a few extra explanatory variables describing characteristics of the destinations and the trip chains) shows that there is a high degree of correlation between the predicted probabilities from the two model versions[17]. However, there are individual deviations that are significant.

Table 4–C shows the results of the linear regression model estimating average vkm per person per day. Some of the indicators from Table 4–B have no significant effect in this model and they are therefore excluded. All the included indicators (explanatory variables) have significant effect at one percent level or lower[18]. Indicators with positive regression coefficient (B) contribute to an increase in vkm, while negative coefficients have the opposite effect.

Table 4-C. Average vkm per person per day. Trip chains starting from home. NTS 2013/14. N=55 468.

	Modell 5				
	B	Std. Error	Beta	t	Sig.
Constant	3,406	0,950	0,000	3,585	0,000
SQRT Inh.(1000)/km2 built-up areas within 1 km	-2,348	0,364	-0,052	-6,449	0,000
SQRT Public transport frequency 07:00-09:00	-0,408	0,144	-0,017	-2,831	0,005
Ln(km) to main regional centre	2,608	0,188	0,087	13,874	0,000
Jobs/residents within 5 minutes driving time	-3,531	0,482	-0,037	-7,330	0,000
SQRT Inhabitants main regional centre (1000)	-0,073	0,019	-0,025	-3,752	0,000
SQRT(Income) (NOK 100,000 / year)	1,151	0,231	0,025	4,980	0,000
Woman	-5,646	0,283	-0,086	-19,979	0,000
Number of children in the household	0,956	0,151	0,028	6,328	0,000
Employed	5,597	0,336	0,082	16,652	0,000
Number of cars in the household	4,015	0,193	0,105	20,800	0,000
Driver's license (dichotomy)	10,548	0,504	0,094	20,946	0,000
Number of persons >= 18 years	-1,089	0,195	-0,025	-5,575	0,000
R^2	0,10				

The regression coefficients B_1, B_2, B_3, …. B_{12} and C (constant) in Table 4–C (model 5) can be used in a formula for estimating predicted vkm per person per day:

---

[16] Nagelkerkes R^2 is a so-called pseudo R^2 and cannot be used to accurately determine the proportion of explained variation in the dependent variable. However, a calculation based on a linear regression model with the predicted probability as an independent variable shows that the proportion of explained variation is approximately 21 per cent.

[17] The fit line in a bivariate scatterplot between the two sets of prediction values goes approximately through the origin and has a slope coefficient of approximately 0,9.

[18] For multicollinearity and correlation, see the footnote for Table 4–B.

$$Predicted\ vkm = \sum_{i=1-12}(B_i \cdot X_i) + C \qquad (2)$$

X_1, X_2, X_3, …. X_{12} represents the independent indicators (explanatory variables) in the first column in the table (Table 4–C). As for the results from the logistic regression models, the formula (2) and the coefficients B_1, B_2, B_3, …. B_{12} in Table 3 are implemented in MST.

The explanatory power of the model (R^2) is no more than ten percent (Table 4–C). This is a consequence of great variance in distance travelled by car as driver per day. The empirical average for vkm/day in NTS 2013/14 is 18,2 km, while the standard deviation is as high as 32,9 km (persons with 0 vkm included). Anyway, a test with integrated bootstrapping with 1000 resamples, shows that the model is robust[19].

High variance in vkm must be seen as a result of a number of random factors for which we do not have any explanatory indicators. One random factor may be that some people had especially much driving on the day of the survey. One way to reduce such effects may be to transform the dependent variable in model 5 to the √(vkm). This increases the explanatory power to 16 percent. However, this variant of the model cannot be used in the MST.

Despite low explanatory power in model 5 (Table 4–C), tests conducted indicate that the predicted values on average give fairly good estimates. This is illustrated in Table 4, where we have compared empirical averages for vkm from NTS 2013/14 with mean values based on the model's predictions for different regions[20], as well as in Table 4–E, which shows a similar comparison for distance zones around the city centre in the Oslo region[21].

Table 4-D. Vkm per day per persons by region. Empirical means and means of predicted values.

Regions	**Average vkm per day per person (NTS 2013/14)**	**Average predicted vkm**
Regions with main regional centres < 25000 inhabitants	20,9	20,7
Regions with main regional centres 25000 – 50000 inhabitants	19,8	19,1
Regions with main regional centres > 50000 inhabitants	19,5	19,6
Twin-city regions*	19,7	19,4
Bergen & Trondheim regions	15,1	16,9
Oslo region	15,0	14,8

[19] Bootstrapping requires analysis without weighting. Without weight indicator 'SQRT Inhabitants main regional centre (1000)' is not a significant explanatory variable. This is due to a skewed geographical distribution of the sample, which relatively gives too many interviews in the metropolitan regions. This bias is eliminated with sample weights in the other analyses.

[20] The predicted values for each region are approximately normally distributed around the mean.

[21] Based on this; if we use the average vkm from NTS 2013/14 per distance zone (as in Table 4–E) per region (as in Table 4–D) – which give a matrix with 36 values ranging from 5 to 60 – as dependent variable in a model corresponding to model 5, we will have R^2=0,82. This of course implies an unrealistic assumption that all persons belonging to a matrix-cell have the same vkm-value.

Table 4-E. Vkm per day per persons by distance to the main regional (city) centre. Oslo region. Empirical means and means of predicted values.

Distance to Oslo city centre	Average vkm per day per person (NTS 2013/14)	Average predicted vkm
0 - 5 km	5,1	2,6
5 - 10 km	12,1	13,5
10 - 20 km	15,1	16,6
20 - 30 km	17,9	20,7
30 - 50 km	27,2	24,2
50 km and more	32,9	25,6

4.2.3. Calculation of emissions and energy

To estimate energy and emissions attributed to the transport generated by dwellers of the future settlement, we first estimate the total vkm generated by dwellers of the planned settlement,[22] and then use projections on the distribution of vkm by powertrain/fuel type for Norway for 2020 calculated by Fridstrøm (2019)[23]. Projections are based on a bottom-up stock-flow cohort model (BIG) that considers different categories of vehicles as well as their weight, age, and powertrain. The model is based on stock data for 2018 and flow intensities calibrated on register data for 2012-2017, and projections are estimated based on two scenarios: one based on the Norwegian National Transport Plan for 2018-2029 (Ministry of Transport, 2017) and one based on the Government's National Budget for 2019 (Ministry of Finance, 2019). The MST builds on the latter[24].

The number of kilometres attributed to each powertrain is, then, multiplied by corresponding factors[25] to estimate final energy consumption and emissions. Energy and emission factors are a function of fuel consumption per km and energy consumption per litre of fuel type[26]. By default, the MST uses the distribution of vkm by powertrain for 2020 and energy and emissions factors shown in Table 4–F. Users are strongly recommended to enter a distribution of vkm by powertrain that reflects the average expected composition of the car fleet in the municipality for the year in which the settlement is expected to be finished. If users are interested in estimating transport related energy use for a 60-year period, changes in distribution of vkm by powertrain over that period should be considered. Factors, however, can only be changed by the tool administrator(s). These should be changed if there are major technological changes that can affect fuel consumption and emissions.

[22] The linear model estimates vkm per person and day, so we multiply this value by 365 (days of the year) and the number of adults expected to reside in the new settlement (in accordance with the settlement's characteristics).
[23] This distribution differs to some degree from the corresponding distribution based on Statistics Norway's reported vkm for passenger cars by type of fuel (table 12577) due to methodological differences between both approaches.
[24] see table V.16 in Fridstrøm (2019).
[25] Factors are based on coefficients used for projections published in Fridstrøm (2019).
[26] Factors for electric vehicles are based on coefficients used for projections in Fridstrøm (2019). Factors for gasoline and diesel based on https://elbil.no/hvor-baerekraftig-er-hydrogen-som-drivstoff.

Table 4-F. Energy consumption (kWh) per kilometre and CO_2 (kg) per kilometre

	Vkm share	*Fuel consumption per km*	*Energy consumption per l of fuel*	*Energy (kWh/km)*	*CO_2 (kg/km)*
Gasoline	25,1	0,829	9,1	7,540	0,192
Diesel	50,6	0,694	10,1	7,010	0,186
Non-plug-in hybrid	3,9	-	-	6,067	0,144
gasoline		0,667	9,1	6,069	
diesel		0,559	10,1	6,048	
Plug-in hybrid	7,2	-	-	6,640	0,155
gasoline		0,632	9,1	6,753	
diesel		0,458	10,1	5,622	
Battery electric	13,1	0	2	2,000	0,000
Hydrogen	0,01	0	0	0,000	0,000

Note that for hybrid vehicles we estimate a weighted factor and consider that the majority of these vehicles – whether these are plug-in or not – run on gasoline (90%). Factors for CO_2emissions are based on estimations used by Fridstrøm (2019). As for energy consumption, we also use a weighted function for estimating carbon emissions of hybrid vehicles.

In sum, the MST estimates the total energy consumption (∑KWh) and the total emissions (∑CO_2) associated to the transport generated by the residents of the settlement using the following formulas:

$$\sum Kwh = 365 \cdot A \ \cdot P \cdot \sum_i \left(f_i \left({}^{Kwh}/_{vkm} \right)_i \right) \qquad (3)$$

$$\sum CO_2 = 365 \cdot A \ \cdot P \cdot \sum_i \left(f_i \left({}^{CO_2}/_{vkm} \right)_i \right) \qquad (4)$$

where A denotes the number of adults in the settlement, P indicates predicted vkm from (2), i is the identifier of energy carrier and f_i measures the share of vkm by energy carrier i.

4.3. Discussion of limitations

As any model, the MST is a **simplification of** a complex **reality** and, as such, it does not account for all possible variables that may affect travel behaviour. Thus, the model includes explanatory variables pertaining socio-economic and demographic as well as contextual characteristics pertaining the settlement itself (where travel starts) including its relative location, but it neither comprises explanatory variables on contextual characteristics of travel destinations (e.g., workplace) and accessibility measures[27] nor considers explicitly residential and transport preferences. Feeding data on these variables into the models may have probably increase the variance explained by the models. On the other hand, this would have added a layer of complexity when it comes to the tool's usability, especially considering that municipal planners and developers do not know who will be moving into the planned settlements.

The latter is certainly a challenge of the MST, as **users are required to make assumptions** about the socio-economic and demographic characteristics of the future residents of the planned

[27] This is a major drawback because studies have shown that workplace's location and its contextual characteristics, and not least the transport (transit) accessibility to the destinations, significantly influence travel mode choices and distances (e.g., Engebretsen et al., 2018; Næss et al., 2017; Strand et al., 2013; Engebretsen 2020; Lunke and Engebretsen 2021).

settlement. While some parameters are relatively stable, other may be more uncertain. Also, some of these assumptions may be ‘influenced’ to some extent by the characteristics of the settlement (e.g., is it designed for accommodating families with children? how many parking spaces provides?).

A drawback of the MST is that the estimation of energy consumption and emissions is based on an estimation of vkm by a **model with a low R^2**. Yet, as indicated above, we have conducted several tests that show that the model is robust and makes accurate estimations.

Moreover, estimation of parameters is based on **travel data collected at national level**, i.e., from a population sample of individuals residing in Norway. Although the sample is considered to be representative (Hjorthol et al., 2014) and despite tests indicating that predicted values give fairly good average estimates, the effects of certain variables on output variables vary greatly from case to case.

Thus, in view of these limitations and challenges we suggest using the MST to compare the implications of developing residential settlements of different characteristics at the same location and settlements of identical characteristics at different locations and not to estimate accurate figures on any of the output variables, particularly not to estimate accurate car vkm and related energy consumption and emissions.

4.4. References

Fufa, S.M., Klinski, M., Azrague, K., Barlindhaug, R., Bußwald, P., Engebretsen, Ø., Finker, C., Landa-Mata, I., Lichtenwöhrer, P., Neugebauer, G., Niederl, F., Stöglehner, G., 2019. *Embodied Energy, Costs and Traffic in Different Settlement Patterns: Background projects and tools* (SINTEF Research No. 61). EE Settlement Project. SINTEF Academic Press, Oslo, NO.

Engebretsen, Ø., 2020. «Tilgjengelighet og transportvalg» in Nordbakke, S., Christiansen, P., Engebretsen, Ø., Grue, B., Lunke, E.B., Krogstad, J.R., 2020. *Akseptable tiltak for mer effektive og miljøvennlige arbeidsreiser.* TØI-report 1779/2020. Institute of Transport Economics, Oslo.

Engebretsen, Ø. 2018. *Måling av trafikkarbeid med reisevaneundersøkelser*. TØI report 1647/2018. Institute of Transport Economics, Oslo.

Engebretsen, Ø., Næss, P. & Strand, A. 2018. *Residential location, workplace location and car driving in four Norwegian cities.* European Planning Studies, Vol. 26, No. 10, 2036-2057

Engebretsen, Ø., Christiansen P. 2011. *Bystruktur og transport. En studie av personreiser i byer og tettsteder.* TØI report 1178/2011. Institute of Transport Economics, Oslo.

Fridstrøm, L. 2019. *Framskriving av kjøretøyparken i samsvar med nasjonalbudsjettet 2019.* TØI-report 1689/2019. Institute of Transport Economics, Oslo.

Hanssen, J.U. & Engebretsen, Ø. 2006. *Turproduksjon for boliger i Oslo og Akershus.* PROSAM-report 137. The Norwegian Public Roads Administration – Region East, Oslo.

Hjorthol, R., Engebretsen, Ø. and Priya Uteng, T. 2014. 2013/14 *National travel survey – key results.* TØI report 1383/2014. Institute of Transport Economics, Oslo.

Landa-Mata, I., Engebretsen, Ø. and Barlindhaug, R., 2018. *Embodied Energy, Costs and Traffic in Different Settlement Patterns Travel behaviour, housing and location preferences.* Edited by Selamawit Mamo Fufa and Michael Klinski. (SINTEF Research No. 56). EE Settlement Project. SINTEF Academic Press, Oslo NO.

Lunke, E.B. & Engebretsen, Ø. 2021. *Tett eller tilgjengelig? En studie av tetthet, tilgjengelighet og reisevaner i Viken og Oslo*. TØI report 1827/2021.Institute of Transport Economics, Oslo.

Ministry of Finance 2019. Meld. St. 1 (2018-2019) – The National Budget 2019. Government.no, Oslo.

Ministry of Transport 2017. Meld. St. 33 (2016–2017) – National Transport Plan 2018–2029. Government.no, Oslo.

Næss, P., Strand, A., Wolday, F. & Stefansdottir, H., 2017. *Residential location, commuting and nonwork travel in two urban areas of different size and with different center structures.* Progress in Planning (2017), http://dx.doi.org/10.1016/j.progress.2017.10.002

Strand, A., Engebretsen, Ø., Kwan Kwong, C., Isberg, L. & Christiansen, P., 2013. *Transportkonsekvenser av ulike utbyggingsalternativer i Regional plan for areal og transport i Oslo og Akershus.* TØI report 1267/2013. Institute of Transport Economics, Oslo.

EE Settlement – Norwegian Model Description

THEORETICAL BACKGROUND, METHODOLOGY, REFERENCE VALUES, AND DATA SOURCES

This report is produced as part of the research project *EE Settlement – Embodied Energy, Costs and Traffic in Different Settlement Patterns*, an international project financed by the Norwegian Research Council under the BYFORSK program. The EE Settlement project seeks to provide guidelines and tools for municipalities, public authorities, professionals, and the public, for evaluating the consequences and impacts of different housing development options.

The EE Settlement project specifically addresses some of the currently overlooked or unquantified aspects of new development projects (or settlements) – the embodied and operational energy, greenhouse gas (GHG) emissions, & direct public costs attributable to buildings, infrastructure, facilities, services, & transport. One output of the EE Settlement project is a web-tool designed to allow users to quickly assess and compare metrics regarding the embodied and operational energy, GHG emissions, and costs related to new settlements.

The objective of this report is to provide an overview of the theoretical background, methodology, reference models, data sources, and limitations for the Norwegian model. This report is intended as a supplement to both the web-tool and the series of reports published under EE Settlement.

SINTEF

SINTEF Academic Press