SINTEF RESEARCH 77

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EE SETTLEMENT FINAL REPORT 2017–2021

SINTEF Research

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EE Settlement final report 2017–2021

SINTEF Academic Press

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EE Settlement final report 2017–2021

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

ISSN 1894-1583
ISBN 978-82-536-1705-3 (pdf)

Project no: 102014481

Front page illustration: Akaryon

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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 by Selamawit Mamo Fufa with contribution from project partners as authors on specific topics.

Oslo, Norway
30.04.2021

Maria Kollberg Thomassen
Research Manager
SINTEF Community

Selamawit Mamo Fufa
Project Manager
SINTEF Community

Contents

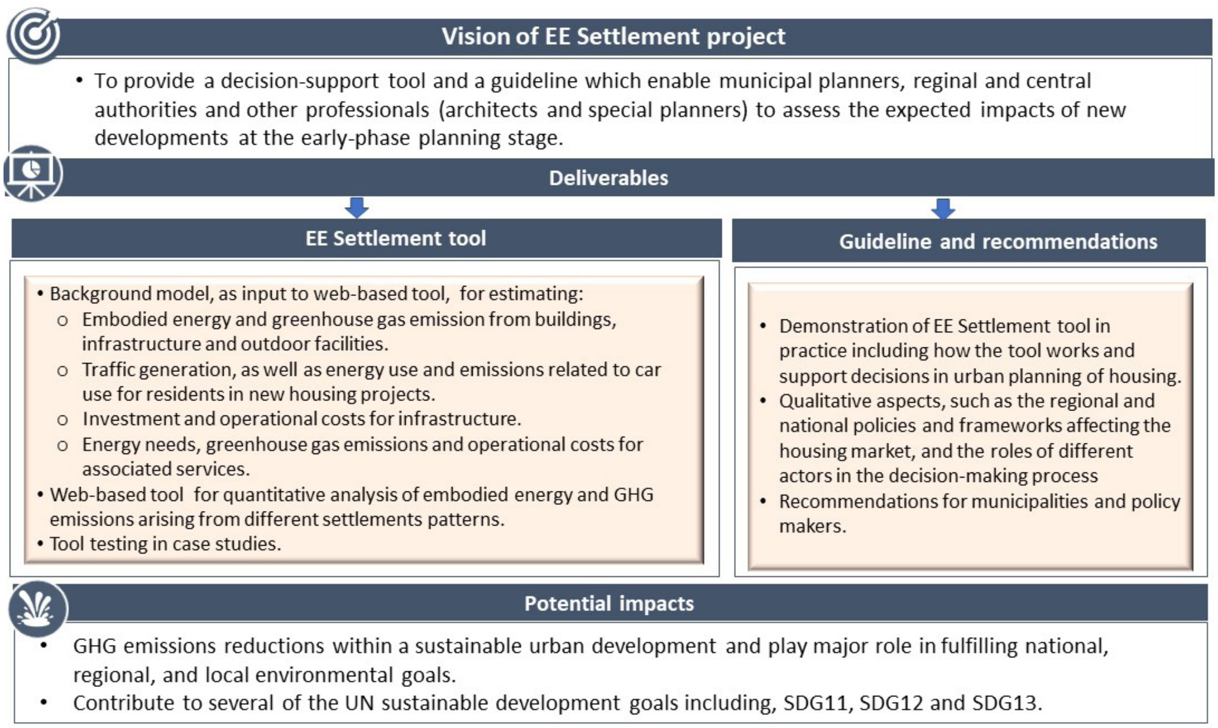
Selamawit Mamo Fufa Senior Research Scientist, SINTEF
Project and work package leader, EE Settlement

EE Settlement project vision

The vision of *EE Settlement – Embodied Energy, Costs and Traffic in Different Settlement Patterns* project is to provide a decision-support tool and a guideline which enable municipal planners and other stakeholders to assess the expected impacts of new developments at the early-phase planning stage. The project aims to:

- Generate profound basic data on the embodied energy requirements of different dwelling types and settlement patterns, including associated outside facilities and infrastructure.
- Assess associated investment, operating costs and energy, and induced transport demand.
- Assess political and societal framework which affects housing development, individual housing preferences, and user decisions.
- Provide a web-based tool and a guideline and recommendations for discussion of spatial planning and housing options, as well as for preparation of political decisions.

The results of this vision are expected to contribute to GHG emissions reductions within a sustainable urban development and play major role in fulfilling national, regional, and local environmental goals.



An overview of EE Settlement project visons, deliverables, and potential impacts (SINTEF).

Background data for embodied energy generated in the project can be very important for the definition and implementation of appropriate policy instruments, especially when assessments considering the political and societal framework as well as the cost of municipal services and generated traffic in different settlement structures.

The EE Settlement web-tool will support county authorities, municipalities, and developers by making the consequences visible when it comes to different options regarding building types, settlement patterns and further development in urban or rural areas. As the tool has been developed in a series of consultations with relevant actors, the project results are expected to have high practical relevance in urban planning.

Furthermore, the results from EE Settlement project contribute to several of the UN sustainable development goals including: SDG11, Sustainable cities and communities, SDG12, Responsible production and consumption, SDG13, Climate action and waste and pollution reduction impacts.

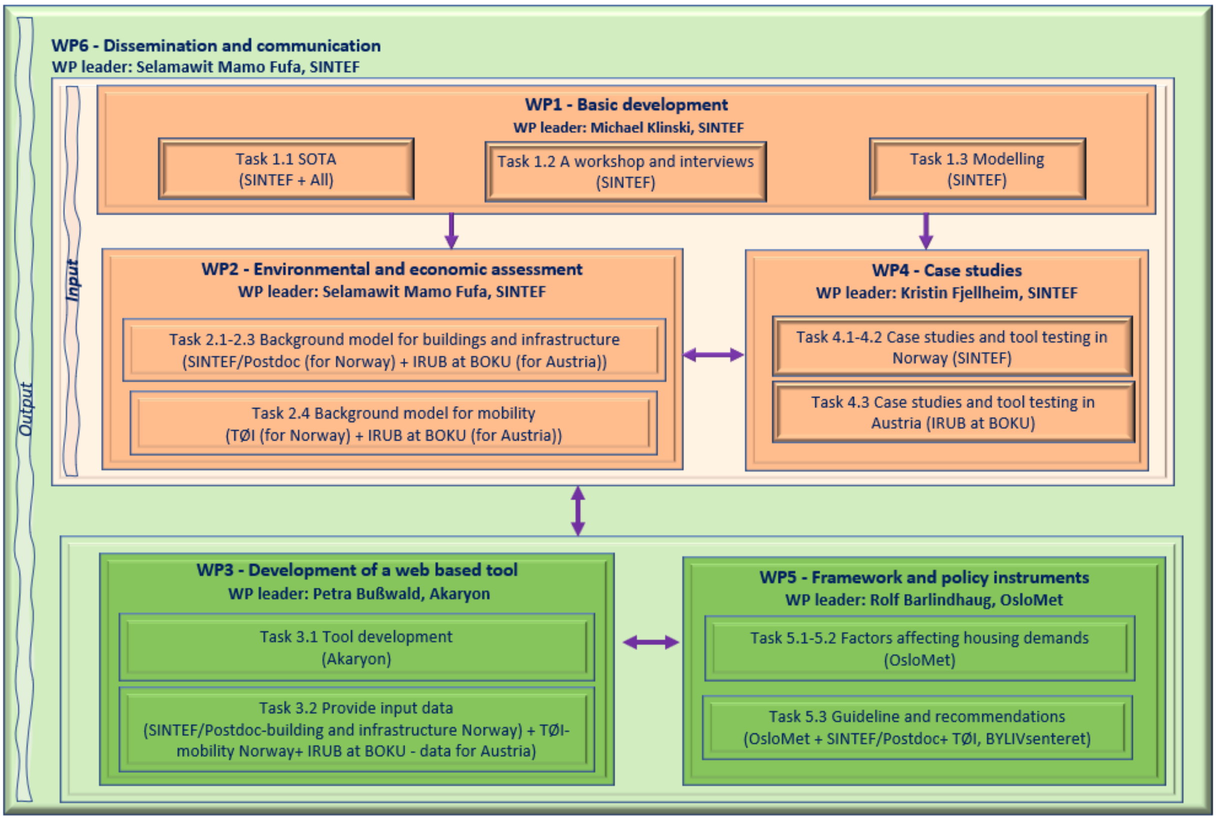
Basic facts about the project

EE Settlement is a research project financed by The Norwegian Research Council through the Byforsk programme for a duration of August 2017–March 2021.

The project started by developing a basis (in WP1), where needs are assessed, and the scope of the project is defined. Environmental impact and economic assessments (in WP2) and the development of a web-based tool (in WP3) buildup on this basis, and assessment results are used as inputs in the tool development and improvement. Case studies (in WP4) are used to quality assure the tool and give inputs for the tool improvement. The project also examines framework conditions and provides guideline and recommendations, based on the needs are identified (in WP1) and project results (from WP2-WP4). All results generated in the project are disseminated through different channels (in WP6).

The project is an interdisciplinary collaboration between SINTEF, Institute for Urban and Regional

Consortium		
Project owner and project leader	*SINTEF Community, Department of Architectural Engineering and Department of Infrastructure*	SINTEF
National research partners	The Norwegian Institute for Urban and Regional Research (*NIBR*), a social science research institute at OsloMet	OSLOMET OSLO METROPOLITAN UNIVERSITY STORBYUNIVERSITETET
	Institute of Transport Economics	tøi Institute of Transport Economics Norwegian Centre for Transport Research
National implementation partners	*Kristiansand municipality*	Kristiansand kommune
	BYLIVsenteret, owned by the National Association of Norwegian Archi-tects (NAL)	National Association of Norwegian Architects
International subcontractor/partners	*Akaryon* – Research based Austrian SME, environmental informatics	akaryon
	University of Natural Resources and Life Sciences, Vienna (*BOKU*), Institute of Spatial Planning, Environmental Planning and Land Rearrangement (*IRUB*)	BOKU IRUB Institute of Spatial Planning, Environmental Planning and Land Rearrangement



EE Settlement project organization plan and partners contribution (SINTEF)

Research (NIBR) at OsloMet, Institute of Transport Economics (TØI), Kristiansand Municipality, BYLIVsenteret owned by the National Association of Architects and two partners from Vienna (Akaryon and IRUB at BOKU), who have previously developed recommendations and tools for Austria.

There have been discussions and collaboration with projects with similar ambitions [FME-ZEN (Zero Emission Neighbourhoods in Smart Cities) and PI-SEC (Planning Instruments for Smart Energy Communities)] during the project period, on sharing and dissemination of information generated in the projects.

Main research activities

The aim of EE Settlement project is to provide a tool, guidelines, and recommendations for municipalities, regional and central authorities, as well as for professionals and other actors, for assessing the consequences and impacts of different housing development options, considering energy consumption, greenhouse gas (GHG) emissions, and costs over the lifecycle of buildings, infrastructure, and transport.

The research activities are categorized into six main work packages (WP) to achieve the aim of EE Settlement project.

WP1
Basic developments:
The aim is to create a basis for identifying the needs and defining define the scope of the project. The main activities include: *a state-of-the-art (SOTA) review of current available tools and studies (Task 1.1), identification and evaluation of the demand of different municipalities and authorities through interviews and a workshop (Task 1.2) and define the goal and scope of the project (Task 1.3).*

WP2
The environmental and economic assessment:
The aim is to assess and develop representative models for buildings, infrastructure, and mobility according to specific indicators defined in WP1. The main activities include the: *calculation of embodied energy and operating energy (Task 2.1), calculation of investment and operating costs for the associated infrastructure (Task 2.2), estimation of energy demand and operating costs for services (Task 2.3), estimation of residents' energy needs for transport (Task 2.4).* The results are

used as input in the development of the EE Settlement web-based tool (in WP3) and guidelines and recommendations (in WP5).

WP3
Development of a web-based tool:
The aim is to develop a web-based tool which enables the assessment of environmental and economic impacts, supporting decision-making concerning different types of housing and settlement developments. The main activities include the: *development of a generic model that can be used in several countries (bilingual) (Task 3.1), adaptation to Norwegian conditions and needs (Task 3.2).*

WP4
Case studies:
The aim is to test the EE Settlement tool in selected Norwegian and Austrian municipalities, conduct quality assurance and improvement of the tool (in WP3), and provide an input for recommendations and guidelines (in WP5). The main activities include: *applying the tool prototype to evaluate case studies from Kristiansand municipality, developing recommendations based on the results (Task 4.1), applying the tool prototype to evaluate case studies from other municipalities and developing recommendations based on the results (Task 4.2), applying the tool prototype in cities in Austria (Task 4.3).*

WP5
Framework and policy instruments:
The aim is to examine framework conditions and develop guidelines and recommendations based on the results from WP2-WP4, considering the needs identified in WP1.The main activities include: *investigating factors that can affect individual and household housing demand and housing location patterns today (Task 5.1), identify instruments that should be used by municipalities and governing authorities to increase the sustainability of settlement patterns (Task 5.2), and to develop recommendations and guidelines for municipalities and policy makers, in light of the results of the project (Task 5.3).*

WP6
Dissemination and communication:
The aim is to disseminate the project findings to different actors. The main activities include: *workshops (Task 6.1), presentations and publications (Task 6.2), and user/public-oriented communication and publications (Task 6.3).*

The following sections gives a general overview of the main achievements from the research activities in EE Settlement projects followed by scientific highlights presented by the individual partners.

Selamawit Mamo Fufa Senior Research Scientist, SINTEF
Project and work package leader, EE Settlement

Summary

The starting point of the EE Settlement project in 2017 was the need for spatial planning tools and guidelines that could be used for planning of new settlements. Two Austrian tools, ZERsiedelt and ELAS, have served as a foundation for the EE Settlement tool development.

Knowledge needs

During the first two years of the project period, the challenges and needs of relevant actors were evaluated through a workshop and interviews (WP1). The objective was to identify the knowledge gap and gather inputs from relevant actors as a basis for the development of the background model (WP2), web-based tool (WP3), guideline and recommendations (WP5), and future dissemination of the project results among user groups (WP6).

From the workshop and interviews, it was determined that municipalities need a simplified "early-phase" option/version of the tool. This option would limit the scope of optimization in the early planning phase of an area development, as a basis for discussion and to enable building a solid foundation for later stages. Several actors emphasized the need for a user friendly and transparent tool, developed using existing acknowledged methodologies (e.g. NS 3720 GHG emission calculation for buildings) and national databases (e.g. data from municipalities, Statistics Norway), that can enable quantification or visualization of the environmental and economic consequences of choosing different area development alternatives in the early planning stage.

The main findings from the workshop and interviews show that there is a need for a decision support tool that can give a more comprehensive picture of the consequences of the development of an area in the early planning stage (Venås and Mellegård 2018). In addition, the findings show the need for a guideline incorporating qualitative aspects, such as social factors, which will not be explicitly addressed within the tool. Two state-of-the-art reviews of existing studies, databases, and tools, one focused on travel behaviour and housing preferences (Landa-Mata et al 2018), and one on district-level tools and databases (Fufa et al 2019), were performed to fill in the gaps in the current approach and bring new insights to the project.

The findings from literature review, workshop and interviews, were used as a background for other WPs to develop the background model, prototype tool and guideline and recommendations. A working document was developed defining the goal and scope of the project based on these findings (Klinski 2018).

Background model and web-tool development

Data structure and background model for buildings, infrastructure and mobility has been developed (WP2) in 2019 in close collaboration with the tool functionality (WP3). The work has consisted of developing two model frameworks, constructions (building and infrastructure) and mobility simulation model, in Excel files with (Kallaos et al 2021):

- The construction model background data included typical constructions (residential and non-residential buildings and infrastructure), operational costs (for road service and water), one-time investment costs (for infrastructure and non-residential buildings) and operational energy, GHG emissions and costs data for public services (water, solid waste, and road services) resulting from the new settlement. The mobility simulation model included estimation of residents' travel mode choice probabilities, as well as energy use and GHG emissions associated with residents' car use (vehicle kilometers) for regional journeys starting in the settlement.

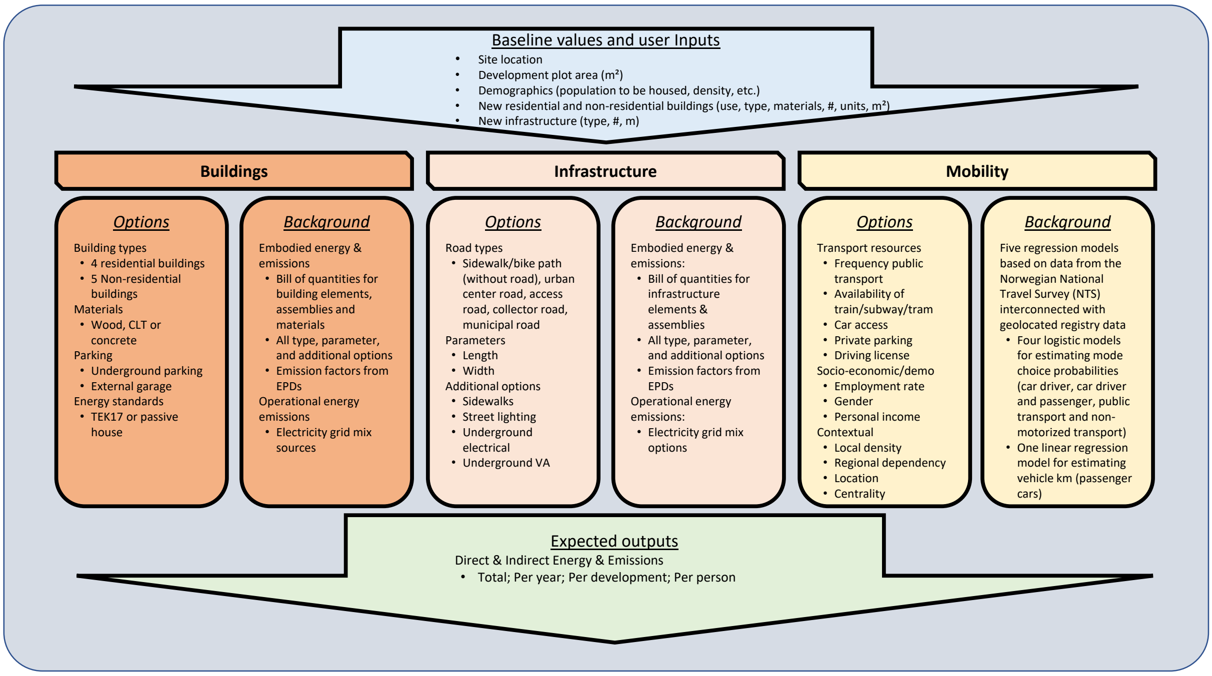
- User inputs including: location; number and type of residential buildings, non-residential buildings, and infrastructure; demography; and mobility related data.
- Model outputs cover embodied energy and GHG emissions from new constructions and mobility demand; operational energy and GHG emissions from new constructions and mobility demand; and the public costs of infrastructure, facilities, and services provided by the host municipality.

The background model is used to develop the first ideas for tool functionality and visual presentation (WP3) in 2019. The prototype tool developed was tested by the partners in a workshop conducted in Autumn 2019. Hamrevann was selected as one of the first case study area from Kristiansand for testing and quality assurance of the prototype tool and the background model (Fjellheim and Fufa 2021). User comments and suggestions were incorporated to further develop the model and the tool.

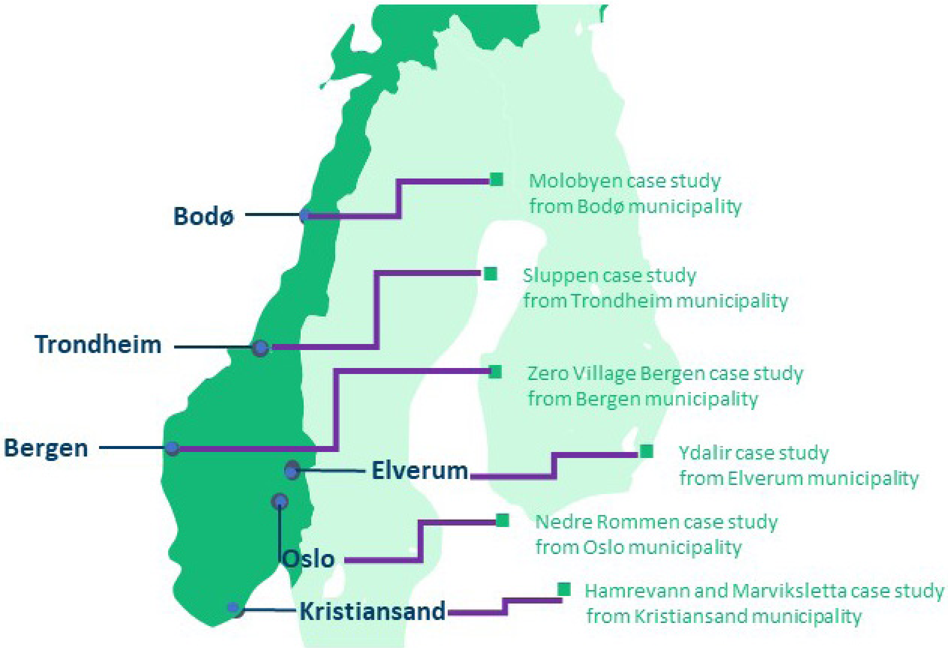
EE Settlement tool testing

In 2020, the project was delayed due to the COVID-19 pandemic. The online tool functionality and visual presentation have been further developed and refined (WP3), with integration of inputs from model changes (WP2) as well as feedback from real-life test cases in Norway (WP4). Tool testing and quality assurance was performed in three Norwegian municipalities (Kristiansand, Elverum, and Bergen) (Fjellheim and Fufa 2021).

The data structure and background model for buildings, infrastructure and mobility were further developed and refined (WP2) in close collaboration with the tool functionality (WP3) (Kallaos et al 2021). A database of Environmental Product Declarations (EPDs) was built to catalog relevant and timely background energy and emissions data for the Excel model framework. These were compiled from different sources, and then simplified, normalized averages were calculated for the different product groups used in the model. These simplified outputs were then fed into the online tool (WP3). Due to the differences in input data between Norway and Austria, a separate model for Austria was developed (WP2) and integrated in the EE Settlement web-tool (WP3).



Background model idea (SINTEF)



Norwegian case studies used for tool testing (SINTEF)

The postdoc working on the project conducted a 5-month research stay abroad at MIT Building Technologies Department. The project has been extended by 3 months into 2021, reflecting both the 5-month postdoc extension as well as a transfer of some research time from 2020 to 2021 due to the pandemic. Final testing of the web-tool in 5 case municipalities from Norway (Kristiansand, Oslo, Elverum, Trondheim and Bodø) and refinement of the model was conducted in 2021.

Guideline and recommendations

The main deliverables of EE Settlement project include a web-tool (WP3) and a guideline and recommendations (WP5). The EE Settlement web-tool is expected to enable end users to perform quantitative assessment of the environmental and economic impact of different settlement patterns (Edelbacher and Bußwald, 2021). The guideline and recommendation focus on showing what the EE Settlement tool can and cannot do, what input data is required and what kind of results are produced (Barlindhaug et al 2021). The guideline also covers qualitative aspects that are not included in the tool, such as structural factors that a market-based development policy provides for house price structure within the current framework conditions and scope of action.

Acknowledgement

The EE Settlement project is funded by the Research Council of Norway through Byforsk program under Grant number 270842. The achievements in the project would not have been possible without the contribution, good collaboration and support of the project partners and the Research Council of Norway. I would like to thank the support from all project partners and the Research Council of Norway.

Selamawit Mamo Fufa Senior Forsker, SINTEF
EE Settlement prosjekt- og arbeidspakkeleder

Sammendrag

Opphavet til at EE Settlement prosjektet ble etablert i 2017 var at man så et behov for arealplanleggingsverktøy og retningslinjer som kunne brukes i planleggingen av nye bosettingsområder. To australske verktøyet, ZERsiedelt og ELAS, dannet grunnlaget for utviklingen av EE Settlement verktøyet.

Kunnskapsbehovet

I løpet av de første to årene av prosjektperioden ble utfordringene og behovene til relevante aktører vurdert gjennom arbeidsmøter og intervjuer (AP1). Målet var å identifisere kunnskapsbehovet og samle input fra relevante aktører som skulle danne grunnlaget for bakgrunnsmodellen (AP2), det web-baserte verktøyet (AP3), veileder og anbefalinger (AP5) og fremtidig formidling av prosjektresultatene blant forskjellige brukergrupper (AP6).

Gjennom arbeidsmøtene og intervjuene ble det identifisert at kommunene trenger en enkel "tidligfase" versjon eller opsjon av verktøyet. Denne opsjonen skulle redusere omfanget av optimeringen i en tidlig planleggingsfase av et bosettingsområde og skulle danne grunnlag for diskusjon og et solid fundament for videre utvikling på senere stadier. Flere aktører fremmet behovet for et brukervennlig og transparent verktøy som bygger på eksisterende og anerkjente metoder (f.eks. NS 3720 for beregning av klimagassutslipp fra bygg) og nasjonale databaser (f.eks. data fra kommunene og SSB) som gjør det mulig å kvantifisere og visualisere de miljømessige og økonomiske konsekvensene av forskjellige alternativer i et tidlig planleggingsstadium i områdeutviklingen.

Hovedfunnene fra arbeidsmøtene og intervjuene viser at det er et behov for et beslutningsstøtteverktøy som kan gi et mer forståelig bilde på konsekvensene av utviklingen av et område i tidlig planleggingsfaser (Venås and Mellegård 2018). I tillegg viste resultatene at det er et behov for en veileder som innlemmer andre kvalitative aspekter som sosiale faktorer, som ikke blir dekket eksplisitt i verktøyet. Det ble gjennomført to state-of-the-art-analyser av eksisterende studier, artikler, databaser og verktøy, en som fokuserte på mobilitet (Landa-Mata et al 2018) og en som fokuserte på verktøy på distriktsnivå (Fufa et al 2019), for å fylle inn hullene i eksisterende tilnærming og for å bringe ny innsikt inn i prosjektet.

Funnene fra litteraturgjennomgangen, arbeidsmøtene og intervjuene ble brukt som bakgrunn inn i de andre arbeidspakkene for å utvikle bakgrunnsmodellen, prototypeverkøyet og veileder med anbefalinger. Et arbeidsdokument ble etablert hvor mål og omfang av prosjektet ble definert basert på disse funnene (Klinski 2018).

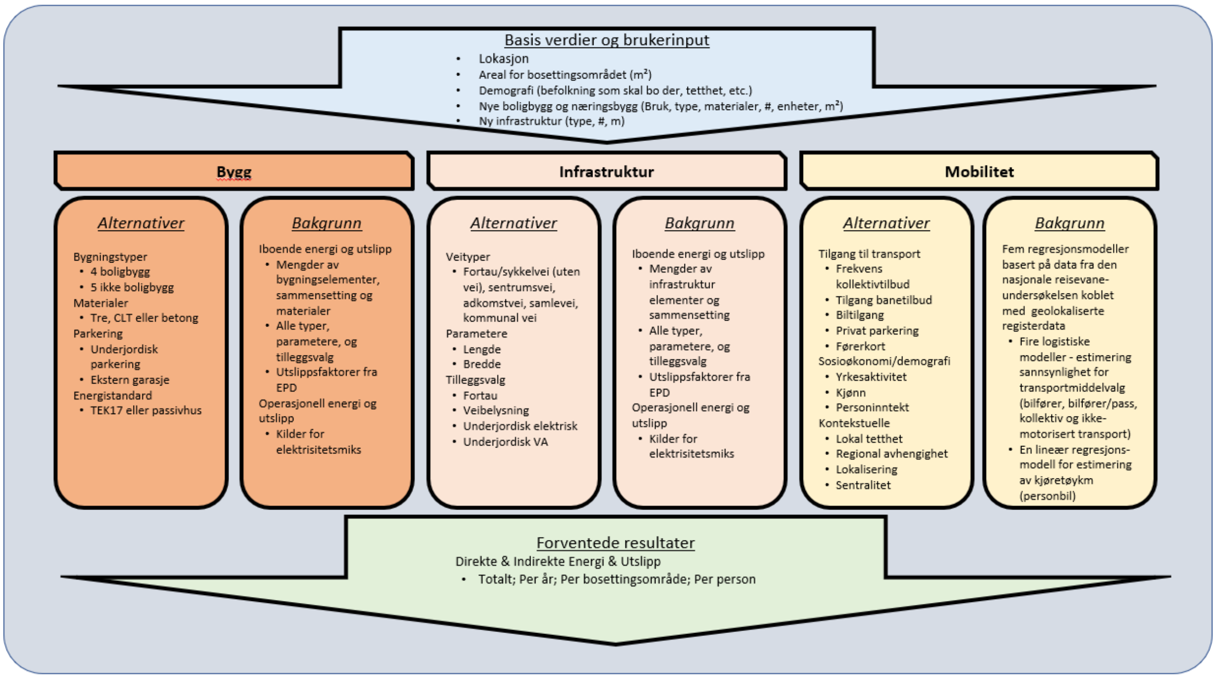
Bakgrunnsmodell og verktøy-utvikling

Datastrukturen og bakgrunnsmodellen for bygg, infrastruktur og mobilitet har blitt utviklet i AP2 i løpet av 2019 i tett samarbeid med utvikling av verktøyfunksjonaliteten (AP3). Arbeidet har bestått i å utvikle to modellrammeverk i Excel med (Kallaos et al 2021) :

- Bakgrunnsdata for typiske bygg, infrastruktur og trafikk
- Brukerinput inkluderer geografisk plassering; antall og type boligbygg, næringsbygg og infrastruktur; demografi og andre mobilitetsrelaterte data.
- Modellresultatene – Iboende energi og klimagassutslipp fra nye konstruksjoner og mobilitetsetterspørsel; operativ energi og klimagassutslipp fra nye konstruksjoner og mobilitetsetterspørsel; kostnader til infrastruktur, fasiliteter og tjenester som tilbys av kommunen.

Bakgrunnsmodellen er brukt for å utvikle den første ideen til funksjonaliteten til verktøyet og det visuelle utrykket (AP3) i 2019. Prototypeverktøyet ble testet av partnere i et arbeidsmøte som ble gjennomført høsten 2019. Hamrevann i Kristiansand kommune ble valgt som det første casestudiet for kvalitetssikring av verktøyet og bakgrunnsmodellen (Fjellheim and Fufa 2021). Kommentarer og forslag fra brukerne ble innlemmet i den videre utviklingen av modellen og verktøyet.

Datastrukturen og bakgrunnsmodellen for bygg, infrastruktur og mobilitet ble videre utviklet og forbedret (AP2) i tett samarbeid med utviklingen av funksjonaliteten til verktøyet (AP3) (Kallaos et al 2021). En database over miljødeklarasjoner (EPD) ble bygget for å danne en katalog med relevante og aktuelle bakgrunns energi- og utslippsdata for Excel modellrammeverket. Disse ble sammenstilt fra flere forskjellige kilder hvorpå dataen ble beregnet for å få forenklede og normaliserte gjennomsnittsverdier for forskjellige produktgrupper brukt i modellen. Disse forenklede verdiene ble så brukt som inputverdier i det web-basert verktøyet (AP3).

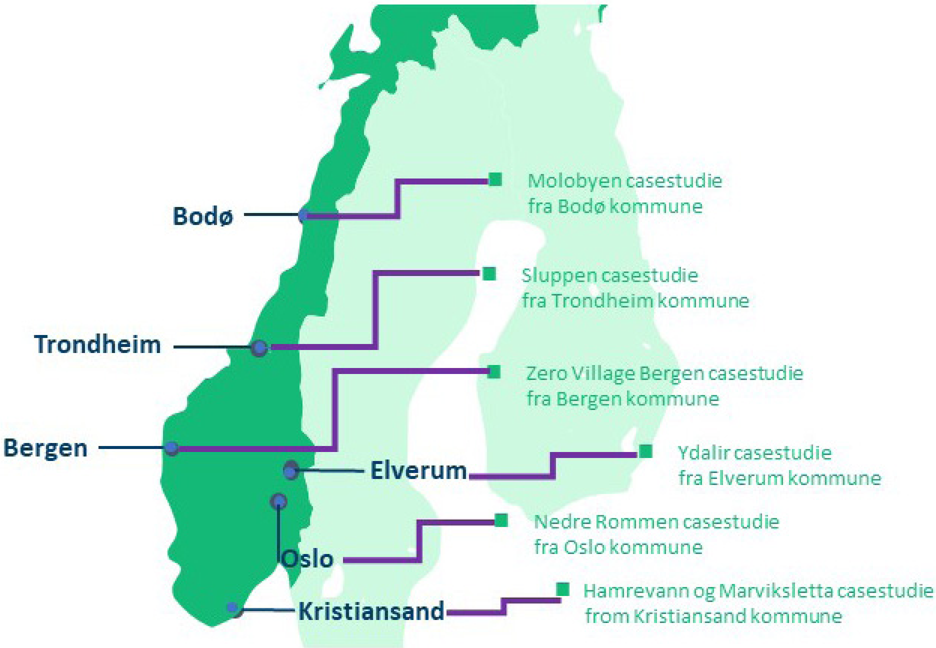


Bakgrunnsmodell ide (SINTEF)

EE Settlement verktøytesting

I 2020 ble prosjektet forsinket grunnet COVID-19 pandemien. Funksjonaliteten og det visuelle utrykket til det web-baserte verktøyet har blitt videre utviklet og forbedret (AP3) med implementering av innspill fra modellendringer (AP2) og gjennom tilbakemeldinger fra reell uttesting av verktøyet i norske og østeriske casestudier (AP4). Uttesting og kvalitetssikring av verktøyet har blitt utført i tre norske kommuner (Kristiansand, Elverum og Bergen) (Fjellheim and Fufa 2021).

Postdoc'en som jobbet i prosjektet gjennomførte et 5 måneders forskningsopphold i utlandet ved MIT Building Technologies Department. Prosjektet har blitt forlenget med tre måneder inn i 2021 som reflekterer både dette 5 måneders oppholdet til postdoc i tillegg til en overføring av forskningstimer fra 2020 til 2021. Avsluttende forbedring av verktøyet og modellen og siste uttesting av verktøyet ble gjennomført på 5 casestudier og kommuner i Norge (Kristiansand, Oslo, Elverum, Trondheim og Bodø) i 2021.



Norske casestudier for uttesting av verktøyet (SINTEF)

Veileder med anbefalinger

Hovedleveransen fra EE Settlement prosjektet inkluderer et web-basert verktøy og en veileder meg anbefalinger. EE Settlement verktøyet skal bidra til at sluttbrukeren kan gjennomføre kvantitative vurdering av økonomisk effekt og miljøpåvirkningen av forskjellige nye bosettingsmønstre (Edelbacher and Bußwald, 2021). Veilederen med anbefalinger fokuserer på å vise hva EE Settlement verktøyet kan og ikke kan løse, hvilken inputdata som kreves og hva slags resultater sluttbrukeren kan forvente å få produsert (Barlindhaug et al 2021). Veilederen dekker også kvalitative aspekter som ikke inngår i det web-baserte verktøyet, for eksempel som strukturelle faktorer som hva en markedsbasert utviklingspolitikk gir i forhold til boligprisstrukturen innenfor gjeldende rammebetingelser og handlingsrom.

Takksigelser

EE Settlement prosjektet er finansiert av Norges forskningsråd gjennom Byforsk programmet under tilskuddssummer 270842. Prestasjonene i prosjektet ville ikke vært mulig uten bidrag fra og godt samarbeid og støtte fra prosjektpartnerne og Norges forskningsråd. Jeg vil gjerne takke for all støtten fra prosjektpartnerne og Norges forskningsråd.

James Kallaos Postdoctoral fellow, SINTEF/OsloMet

From operational to embodied energy and emissions

In the quest to reduce emissions of greenhouse gases (GHGs), focus has rightfully fallen on the building and construction sector. The buildings and construction sector accounted for 38% of global (energy-related) CO_2 emissions in 2019 (UNEP 2020). Residential buildings alone are the largest part of the buildings sector "in terms of floor area (80%), final energy use (70%) and CO_2 emissions (60%)" (IEA 2021, p. 159), representing "the most important product of the construction industry, both in terms of revenue and emissions" (IRP 2020, p. 38). Countries around the world have focused their policy decisions mainly on operational energy, usually measured as an efficiency per area. Putting the focus on building operation and efficiency overlooks many important aspects about buildings and energy. Several important yet overlooked aspects include:

- the number of buildings is not static, but grows every year,
- the size of living space has been increasing, while the number of people per household has been decreasing,
- energy is required, and emissions produced, to manufacture the materials, elements, and assemblies which are used to create the building,
- new housing may require changes, extensions, or upgrades to the existing infrastructure network,
- the location of new housing affects transport modal choice, and
- location and proximity to services affects total travel distance, as well as the energy and emissions from transportation.

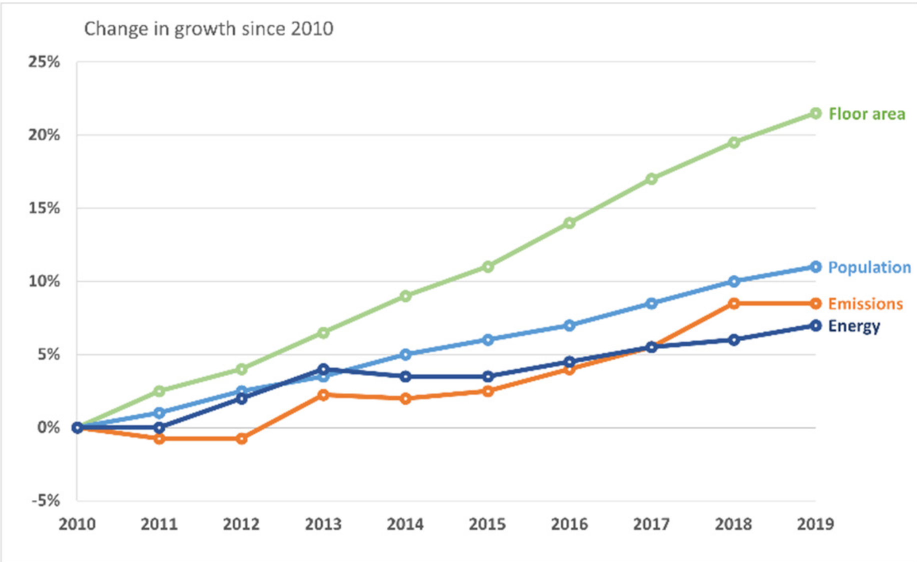
Here we will focus on the first four points above, while the EE Settlement project addresses all six. The energy and emissions that are used or emitted during the production of materials or components

A1-A3 Product Stage			Construction Process Stage		B1-B7 Use Stage							C1-C4 End of Life stage				Benefits and loads beyond the system			
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D1	D2	D3	D4
Raw Material Supply	Transport to Manufacturer	Manufacturing	Transport to building site	Installation into building	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction / demolition	Transport to end of life	Waste Processing	Disposal	Reuse	Recovery	Recycling	Exported energy / Potential

EN 15978 (2011) Life cycle stages/modules are known as embodied energy and embodied emissions. The embodied energy and emissions likely occurred in another sector, and possibly a different country. The transportation of that product to the site where it will be used is also part of the embodied calculation. The nomenclature and categorization of the life-cycle stages for calculating the energy and emissions associated with buildings and infrastructure is formalized in the EN 15978 (2011) standard.

As the number of buildings and quantity of new infrastructure grows, so do the embodied energy and emissions. As the size of each living space increases, so do both embodied and operational energy and emissions. New developments further from existing services require an initial outlay of embodied materials, energy, and emissions for the new infrastructure, as well as continuous costs for maintenance and operations.

The EE Settlement tool can be used in several different ways to help illuminate some of the overlooked aspects of energy and emissions related to new development projects or settlements. It can be used to assess the embodied energy, GHG emissions, costs, and generated traffic of a proposed new development or settlement. It can be used to compare two settlements in the same locations, but with different characteristics (e.g., different building types or overall density). It can be used to compare similar settlements placed in different locations. It can also be used to compare different settlements in different locations, if the user chooses.



Change in global drivers of trends in buildings energy and emissions 2010-2019 (UNEP 2020, p. 19)

Øystein Engebretsen Senior Research Geographer, TØI

Iratxe Landa-Mata Research officer, TØI

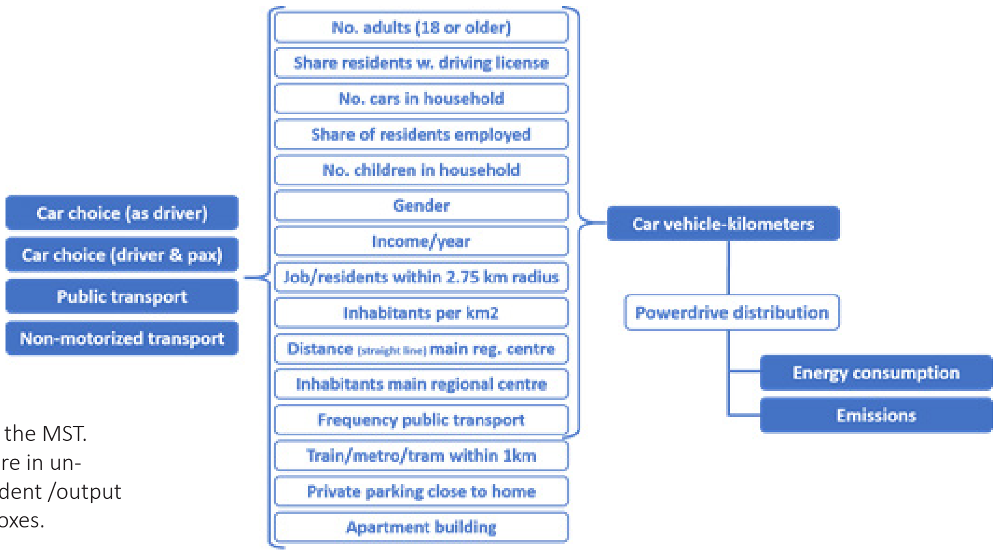
Mobility simulation

The Institute of Transport Economics' main contribution to the project has been to develop a mobility simulation tool (MST) which is an integrated module in the EE-tool. MST estimates the transport mode choice probabilities of residents for journeys starting in the planned residential[1] settlement, daily car vehicle kilometres (vkm) 'generated' by residents (as drivers) linked to the planned settlement and energy consumption and emissions associated to the latter (car vkm).

The mobility model behind the MST builds on five regression models. Default values and parameters of these five models were calculated using multivariate regression analyses conducted on geolocated survey-based travel data from the Norwegian National Transport Survey 2013–2014 coupled with registry data and map data (GIS) measuring output and explanatory variables. The selection of these variables is grounded on existing literature on factors explaining travel behaviour, b, and also depends on data availability, significance (according to regression analyses) and how easy it is for the users (of the EE Settlement web-tool) to obtain data.

The estimation of transport related energy consumption and emissions is a function of estimated car vkm and their distribution by vehicle power train. The number of kilometres attributed to each powertrain is multiplied by corresponding factors to estimate final energy consumption and emissions. Distribution of car vkm by power train and energy and emission factors are based on estimations made and coefficients used by The Institute of Transport Economics (Fridstrøm, TØI-report 1689/2019). The Figure below illustrates the structure of the model.

The model structure illustrated in the figure below is formalized through an Excel-tool. The input values on explanatory variables are based on a combination of data retrieved from other parts of the EE-tool, automatically retrieved API-based data, data entered by the user and/or default average values. Estimated output values on dependent variables are included as part of the total effects calculated in the EE Settlement web-tool – but can also be read separately (as effects of the estimated residents' mobility choices). More information on the MST is provided in the Norwegian model description report (Kallaos et al 2021).



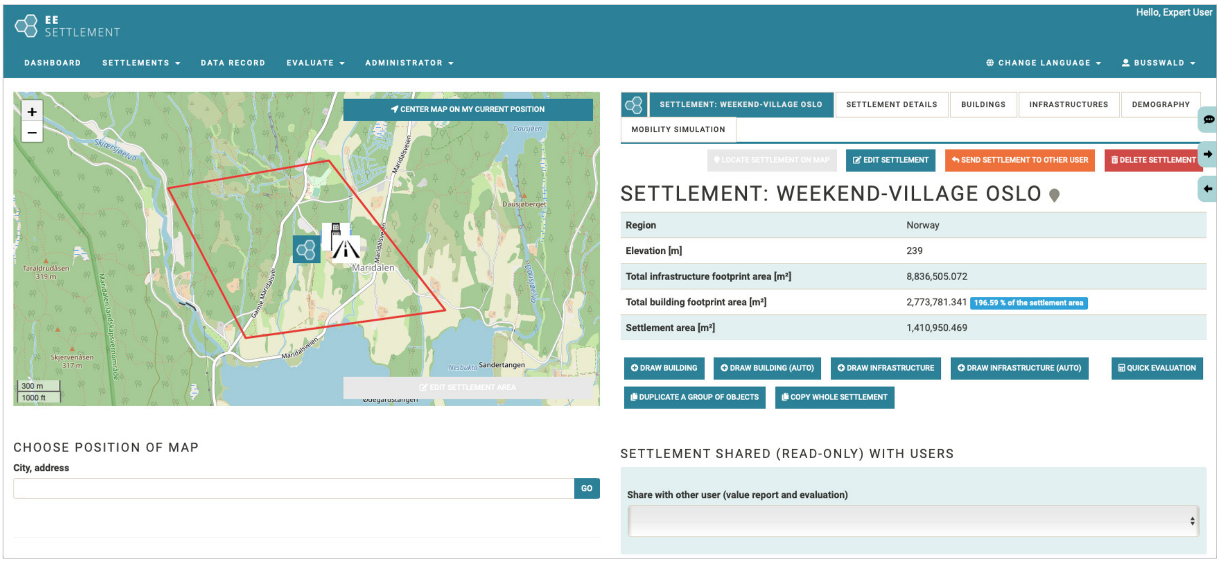
Mobility model behind the MST. Explanatory variables are in uncoloured boxes, dependent /output variables in coloured boxes.

[1] Excludes long distance travel and driving outside the region

Petra Bußwald Managing director, Akaryon
Work package leader, EE Settlement

The EE Settlement tool

The web-based EE Settlement tool, developed within this project, can build the ground for a broad sustainability assessment functionality for settlements.



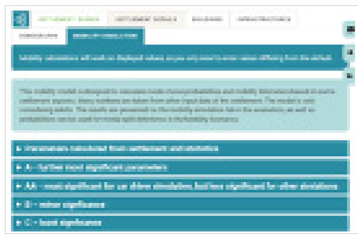
Generating a settlement and its input data

Users can easily navigate on the world map to the desired settlement location and draw a polygon to indicate the area where the settlement shall be built.

The following object categories can be placed into the settlement:

- Residential buildings
- Non-residential buildings
- Infrastructure objects (roads)

For each of these object categories, different types (e.g. single family house or apartment block for residential buildings; e.g. road types for infrastructure objects) are included in the database. These types can be selected by the user and customized



by setting of parameters (e.g. size of the building, number of stories, structural material used) or length and width of the road for example.

In addition to the objects, parameters for demography, mobility and municipal services can be added via dedicated tool pages.

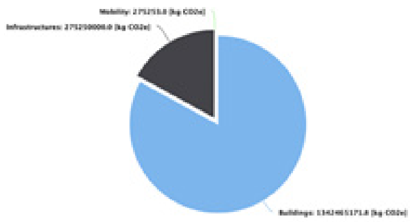
To ease settlement setup, the tool comes with default values depending on the location.

Analysing results

For settlements generated like this, **indicators characterizing the impacts of the settlement** are calculated thanks to mathematical/LCA-models and database content:

- **Quantities** (e.g., degree of soil sealing)
- **Energy** (embodied energy of buildings and streets, operational energy demands and energy demand for mobility and municipal services of/for the inhabitants of the settlement)
- **Greenhouse gas (GHG)** emissions connected with the materials and energy demands
- **Operational costs** (for energy and services).

All outputs are produced in the form of charts and tables with pre-defined reports as well as individual dynamic output generation



How to use the tool and for which use cases?

To use the EE Settlement tool, self-registration is foreseen. Norwegian, English and German language interfaces are available at the moment. Further language version could be added easily in the future.

The user can then come back at any time and edit, save, and assess several settlements. It is also possible to compare settlements and to share settlement data among users. The tool offers a "standard mode" for the beginning and "expert" features can be activated in the profile if the users feel fit enough to get to the next level.

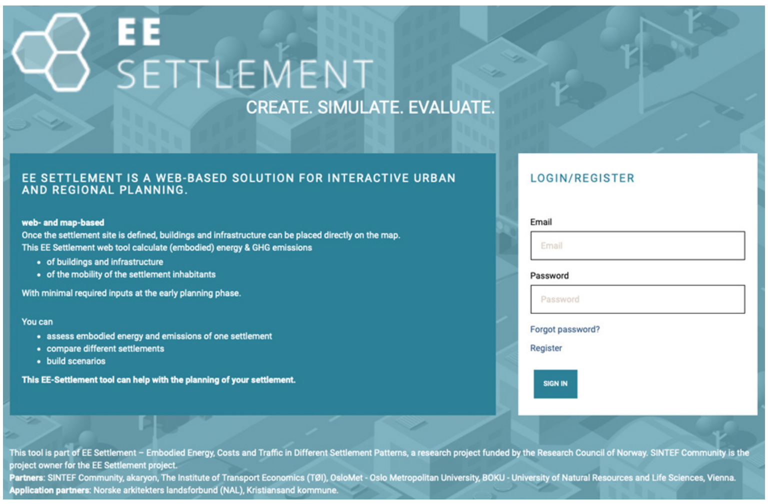
On-spot help information is provided at many parts of the tool.

An English language user guide is available to help the user get acquainted with the functions of the tool (Edelbacher and Bußwald, 2021).

Regionalization

The database includes model data for the Norwegian and the Austrian case, due to the partner constellation in this project. However, settlements of other countries can also be assessed, as country-specific default parameters can be overruled by any user. A value report automatically generates a documentation of all default and user-provided data used.

The tool can be enlarged to specifically cover other country model data, as the database is already prepared to handle such regional variations and an administrative backend is provided.



Kristin Fjellheim Research Scientist, SINTEF
Work package leader, EE Settlement

Lessons learned from Norwegian case studies

The main goal of performing case study tool testing with Norwegian case studies was to get insight into how the tool performs when being used by the end-users and how it can be applied as a decision support tool in their field of work (Fjellheim and Fufa 2021). There were three rounds of testing of the tool from 2019 to 2021 with seven different case studies, six different municipalities and a total of 20 interviewees.

Another area in Kristiansand municipality was chosen to be used as comparative assessment with Hamrevann, this was the Marviksletta case study. This development area had planned for 515 apartments, but to be able to make a comparative assessment with Hamrevann it was assumed that there were also 300 dwellings in this area. The main goal of the comparative assessment was to show how the tool could be used to identify differences between two different settlements with regards to energy consumption and GHG emissions per square meter or per resident.

Marviksletta, Kristiansand municipality

Hamrevann, Kristiansand municipality

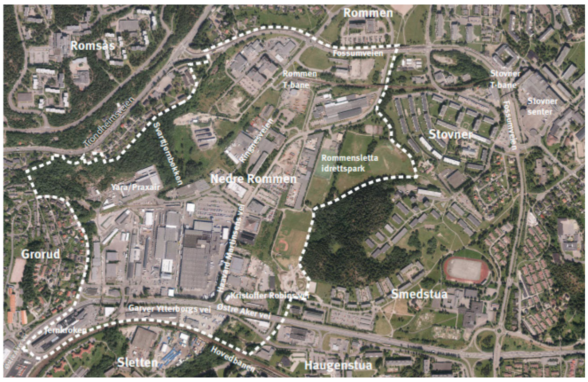
In addition to the main case study there were 5 other case studies where the tool functionality was tested. The Ydalir case study in Eleverum municipality was tested both in 2020 and 2021 and used for testing two scenarios with changes to the building standard (passive house vs TEK 17).

Three case studies were conducted only in 2021 close to project closing in order to do a final check and update of the functionality of the tool. These cases were Molobyen in Bodø municipality, Nedre Rommen in Oslo municipality and Sluppen in Trondheim municipality.

Ydalir,
Elverum municipality

Molobyen, Bodø municipality

The case studies show that for the urban planners, the tool could potentially give important answers for evaluating and comparing different housing developments in the municipality. The results show that the municipalities see the use of this type of tool in the work they do when planning area developments. This is both because they are required in more and more cases to report on greenhouse gas emissions related to the plans they propose, and because it can give an indication of which types of developments will be more beneficial than others with regards to mobility, demography, density and ultimately emissions.



Nedre Rommen, Oslo municipality

The availability of data input will vary depending on which stage of the planning the municipality is considering. For the case studies that was in very early planning phase some of the required data input was not decided upon and many assumptions would have to be made. The potential for the tool to assess alternative configurations and measures for a specific settlement plot is important, by helping them to evaluate how different measures affect the environmental performance of the settlement.

Several of the municipalities had developed very ambitious environmental and energy plans. Documenting the progress of the municipality in relation to achieving these ambitious plans is something the tool could help them with.

Sluppen, Trondheim municipality

Georg Neugebauer Senior Scientist, IRUB at BOKU

Peter Lichtenwöhrer Scientific project staff, IRUB at BOKU

Experience from Austrian model and case studies

Experiences from previous research projects

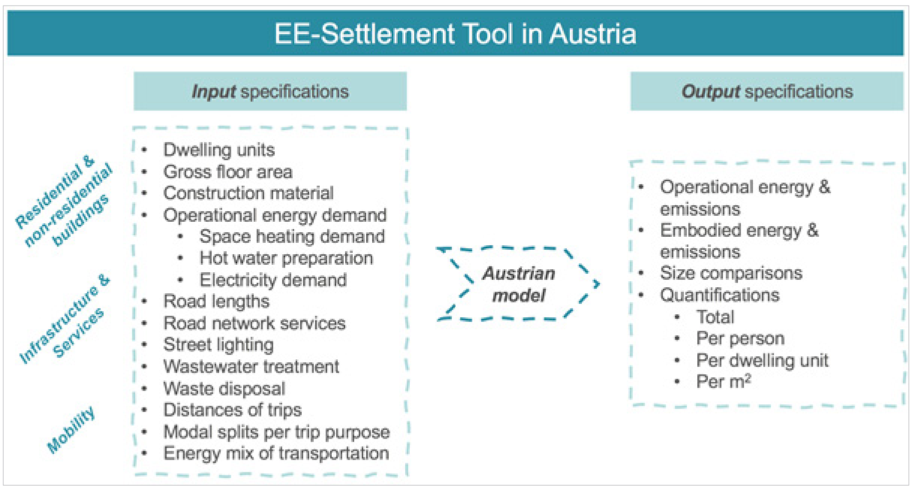
As a starting point for the modelling and application process of the EE Settlement tool, relevant prior research projects were evaluated. The Institute of Spatial Planning, Environmental Planning and Land Rearrangement (IRUB) elaborated relevant principles and methodologies of tools applied in integrated spatial and energy planning in Austria, with a special focus on the ELAS calculator. A summary of the results is presented in (Fufa et al 2019). Experiences from the ELAS calculator (Stoeglehner et al., 2014; Stöglehner et al., 2011) in terms of energy demand, CO_2 life cycle emissions and regional economic impacts of entire settlements were crucial for the adaptations of the Austrian model and the final case study application.

Case study selection in Austria

Prior to the case study evaluation in Austria, possible relevant case studies were identified and selected. Starting point for the selection process was a specifically defined set of criteria which allowed a determination of potential case study candidates. The criteria include for instance the size of municipalities, recent and projected population dynamics, spatial archetypes or activities with respect to spatial planning (e.g. current preparation or adaptation of land use plans). With the final set of criteria, a total of eight case study candidates were determined, from which three were shortlisted. The three final case studies comprise a small residential settlement in a rural municipality, a settlement with both residential and non-residential buildings close to a district capital and a large development area in an urban setting. The chosen case studies were then evaluated using the EE Settlement tool. But before an appropriate evaluation was possible, adaptations of the Norwegian model were necessary in order to generate representative results in an Austrian context.

Adaptations of the EE Settlement model and case study evaluations

Changes and adaptations of the Norwegian model were especially required for the building typology (including different construction materials or different types of operational energy demands), for infrastructure and services and for mobility. An overview of required inputs and essential outputs of the Austrian model is illustrated in Figure below.



Input and output specifications of the adapted Austrian model (own illustration)

Rolf Barlindhaug Researcher, OsloMet
Work package leader, EE Settlement

How can the EE Settlement tool be used in the early planning phase?

The most important results from the EE Settlement project are the web-tool and the report with guidelines and recommendations to help governments and professionals in their efforts to make urban and regional development more sustainable. An important purpose is to show what the tool can actually do, what limitations are in the tool, how the tool can be used in practice and what factors that additionally need to be taken into account in municipal planning processes, but which are not covered by the tool. It is primarily in the preparation of the municipal master plan and the area part of this plan the tool is relevant to use. In addition, the tool provides municipalities with opportunities to vary parameters in a relevant development area, and to calculate the effects of such changes. The target group for the report is primarily authorities at the regional and municipal level.

Our starting point is the UN Sustainable Development Goals, and Norway's adherence to the Paris Agreement with the goal of reducing greenhouse gas emissions by at least 50%, and up to 55% by 2030 compared to 1990. The targets for 2030 and 2050 are legislated through a climate law that came into force on 1 January 2018. The purpose of the act is to promote the implementation of Norway's climate targets as part of the transition to a low-emission society by 2050. This is the background to the work to develop a tool that can consequently calculate embodied energy and greenhouse gas emissions as a result of various settlement patterns,investments in construction and infrastructure, as well as mobility and operating costs over time.

Norway has a deregulated housing market, where the state sets framework conditions for the actors, municipalities are given planning authority and private actors account for property development and housing construction. The municipalities relate to national and regional framework conditions and are responsible for the overall area planning in their municipality. Private landowners and builders can make proposals for zoning regulations in detailed zoning plans, which must be adopted by the municipalities before they can apply for a building permit. Government agencies account for a very small part of housing construction, limited to the construction of a smaller number of homes for disadvantaged and elderly, often housing that needs to be planned in relation to services. Private operators account for most of the housing construction. Both new and second-hand homes are sold at market prices.

The tool does not provide information on the social consequences of various development patterns, such as that central densification projects have high square meter prices so that the homes are not available to households with low incomes. Development in the city's edge zones provides homes with relatively low sales prices, and which are therefore available for a wider range of buying groups. Such conditions must be part of the municipal decision-making substrate, an information basis that cannot be provided by the calculation tool itself. There are therefore a number of factors that municipalities must take into account in the area planning that is not covered by the tool. The municipalities must also ensure that the desired projects are carried out, which assumes that there is demand and willingness to pay for the types of dwellings offered in different locations. Put another way: Municipalities must take into account the population's housing and residence preferences in their planning.

Knut Felberg Municipal manager for climate and area development in Kristiansand municipality

What do municipalities and other public actors achieve by using the research finidings from EE Settlement project?

There has been a need for a user-friendly tool for discussions of spatial planning options, typological, structural and morphological issues in a pre-project or early planning stage, and for the City of Kristiansand the EE Settlement tool has a great potential. Participating in the project has been a rewarding learning experience, and it has been useful and inspiring to work with both the Hamrevann case study and the Marviksletta case study where the outputs have been somewhat surprising and enlightening.

There would ideally be a need for incorporating more qualitative aspects in the tool as well, and we see that it would be important to establish a system of super-users who would be a part of a national or international network. The latter would be a success criterion since the number of situations where there is a real opportunity for concept testing at the pre-project/early planning stage is rather small. But, in the situations where there is an opportunity for testing, EE Settlement would cover our needs. We assume that the implementation of the tool in our processes would provide a sound basis for both the administrative case preparation and political decision making. The completion of the case studies supports this assumption.

Photo: Hamrevann AS

Selamawit Mamo Fufa Senior Research Scientist, SINTEF
Project and work package leader, EE Settlement

Conclusion and future research aspects

The EE Settlement project has enabled multidisciplinary research and collaboration between national and international experts. The collaboration between the Norwegian and Austrian partners has been an important knowledge transfer platform in the project. By real-life testing of applied research findings together with potential end users, insights of the actual application of the research findings and their potential impacts are provided.

Planning of new urban developments at the earlyphase planning stage is a complex task and it has been challenging to include many relevant aspects in the project. EE Settlement project results are in line with the overall project vision, to provide a decision support tool and a guideline which enable municipal planners and other stakeholders to assess the expected impacts of new developments at the early-phase planning stage. The EE Settlement web-tool testing in the selected case studies shows that the tool has received positive feedback from the actual end users involved in the tool testing. The tool is described as a good source of default input values in the early planning phase and a potential decision support tool to assess the environmental impact of alternative settlement options. The tool is also described as an enabler to document and follow up the environmental ambitions of municipalities through evaluation of the performance of different development areas in the early planning phase.

However, partners and participants of the tool testing pointed out to several areas that need further improvements. For example, in the EE Settlement web-tool, even though there is a map for placing out buildings and infrastructures, there is very limited exploitation of the geographical dimension within the tool. The tool is used mainly for calculating the environmental aspects, not for planning and drawing the settlement and settlement pattern. The EE Settlement web-tool is also enabled to evaluate only new developments and it is not possible to evaluate renovation, upgrading, adaptive reuse or transformation of existing settlements. Given that most of the building stock for the next 30 years already exists today, such developments are important path for cities to achieve more sustainable future. The need for similar tools and guidelines for the evaluation of existing settlements has been suggested by different user groups during the tool testing.

The lessons from EE Settlement project will be an inspiration and a steppingstone for new research activities and further development of the missing areas. There are on-going activities on developing new spin-off project ideas to fill in the research gap.

Appendix 1
Main project participants

Main project participants and their role

Project leaders	Selamawit Mamo Fufa, *project leader, SINTEF*	2019–2021
	Sofie Mellegård, ***project leader, SINTEF***	2018 –2019
	Michael Klinski, *project leader, SINTEF*	2017–2018
WP leaders and project participants	Michael Klinski, SINTEF, *WP1 leader and project participant*	2017–2018
	Selamawit Mamo Fufa, SINTEF, *WP2 leader and project participant*	2017–2021
	Petra Bußwald, Akaryon, Akaryon, *WP3 leader and project participant*	2017–2021
	Reidun Dahl Schlanbusch, SINTEF, *WP4 leader and project participant*	2017
	Christoffer Venås, SINTEF, *WP4 leader and project participant*	2018–2020
	Kristin Fjellheim, SINTEF, *WP4 leader and project participant*	2021
	Rolf Barlindhaug, NIBR, *WP5 leader and project participant*	2017–2021
	Sofie Mellegård, SINTEF, *WP6 leader and project participant*	2017–2019
	Selamawit Mamo Fufa, SINTEF, *WP6 leader, contributor to the web-based tool development (WP3, Task 3.2), Norwegian case studies (WP4, Task 4.1) and the guidelines and recommendations report (WP5, Task 5.3)*	2019–2021
Project participants	James Kallaos, Postdoc, OsloMet/SINTEF, *Norwegian construction model developer (WP2, Task 2.1-2.3), contributor to the web-based tool development (WP3, Task 3.2) and the guidelines and recommendations report (WP5, Task 5.3)*	2018–2021
	Kamal Azrague, SINTEF, *Contribution to infrastructure model development (WP2, Task 2.1-2.3)*	2017–2021
	Øystein Engebretsen, TØI, *developer of mobility simulation model (WP2, Task 2.4), contributor to the web-based tool development (WP3, Task 3.2) and the guidelines and recommendations report (WP5, Task 5.3)*	2017–2021
	Iratxe Landa-Mata, TØI, *developer of mobility simulation model (WP2, Task 2.4), contributor to the web-based tool development (WP3, Task 3.2) and the guidelines and recommendations report (WP5, Task 5.3)*	2017–2021
	Erik Sandsmark, Kristiansand kommune, *contributor to input data to the background model (WP2, Task2.1-2.4) and tool testing (WP4, Task 4.1)*	2017–2021
	Knut Felberg, Kristiansand kommune, *contributor to input to data to the background model (WP2, Task2.1-2.4) and tool testing (WP4, Task 4.1)*	2017–2021
	Øystein Bull-Hansen, BYLIVsenteret, *contributor to the development of the web-tool (WP3, Task 3.2) and the guidelines and recommendations report (WP5, Task 5.3)*	2017–2020
	Eva Storrusten, BYLIVsentret, *contributor to the guidelines and recommendations report (WP5, Task 5.3)*	2021
	Peter Lichtenwöhrer, IRUB, at BOKU, *developer of Austrian model (WP2, Task 2.1-2.4 for Austrian case) and responsible to Austrian case studies (WP4, Task 4.3)*	2017–2020
	Georg Neugebauer, IRUB, at BOKU, *developer of Austrian model (WP2, Task 2.1-2.4 for Austrian case) and responsible to Austrian case studies (WP4, Task 4.3)*	2017–2020
Other project contributors	Hanne Liland Bottolfsen, SINTEF, *contributor to residential and non-residential building model development (WP2, Task 2.1)*	2019–2020
	Karin Denizou, SINTEF, *contributor to the guidelines and recommendations report (WP5, Task 5.3)*	2019–2021
	Christian Finker, Akaryon, *contributor to development of the web- tool (WP3, Task 3.1)*	2019–2021
	Jan Erik Lindjord, Kristiansand municipality, *contribution to input to the background model (WP2, Task2.1-2.4) and tool testing (WP4, Task 4.1)*	2019–2021

EE Settlement final report 2017–2021

This is the final report of the research project *EE Settlement – Embodied, energy, costs and Traffic in different Settlement Patterns* financed by The Norwegian Research Council under the BYFORSK program.

The main objective of EE Settlement project is to provide a tool and guidelines for municipalities, regional and central authorities, as well as for professionals and other actors, for assessing the consequences and impacts of different housing development options, considering energy need, environmental impact, and costs over the lifecycle of buildings, infrastructure, and transport.

This report aims to give an overview of the main research activities and deliverables generated by the project partners throughout the project duration of August 2017 – March 2021 to achieve the vision of the project.

SINTEF Academic Press