ASTUS TRANSNATIONAL METHODOLOGY FOR LOW CO_2 SCENARIOS

Project Output O.T2.2

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1. Introduction

With an increasing awareness of the negative consequences of climate change, reductions in greenhouse gas emissions have gained importance on the political agenda. In 2015, the total CO_2 emissions in the European Union (EU) were 22 % below 1990 levels (European Environment Agency, 2017, pp. 71-72). On the contrary, transport-related emissions have increased during the same period. Road transportation accounts for 24 % of total CO_2 emissions in the EU, making it the second largest key source category (European Environment Agency, 2017, p. 73).

This upward trend of transport-related CO_2 emissions seems to be difficult to break and the large gap between projected and desired emission trajectories highlights the magnitude of change required (Hickman et al., 2009; Hickman et al., 2011; Hickman et al., 2012). Economic and social benefits of mobility, paired with affordable and fast transport means induce more travel, while negative side effects become increasingly evident (Banister et al., 2011; Bertolini, 2017).

In line with requests for "decarbonizing" transport (Banister et al., 2011), the European Commission adopted a White Paper on transport in 2011. The aim is to limit oil dependence and to decrease transport-related greenhouse gas emissions by 60% by 2050 on a 1990 base (European Commission, 2011). Concrete emission reduction targets are an important requirement for low carbon transport and effective policy-making processes are crucial in order to be able to meet these targets.

Priority 2 of the Interreg Alpine Space program focuses on low carbon policy instruments and low carbon mobility. The project ASTUS – Alpine Smart Transport and Urbanism Strategies helps local authorities to identify and implement land use and transport planning solutions in order to reduce CO_2 emissions from everyday travel in the Alpine Space. This guideline is part of O.T2.2 ASTUS transnational methodology for low CO_2 scenarios. The methodology introduced in the following sections aims to support territories in finding their own specific pathway towards a low carbon transport future. Section 2 presents the methodological framework: It identifies key influencing factors on transport-related emissions and outlines the basic steps towards developing low CO_2 scenarios. The subsequent section 3 highlights the main requirements for successfully implementing the presented approach. Sections 4, 5, and 6 are dedicated to the CO_{2L}, a transnational tool consisting of a calculation sheet, input data, and a collection of land use and transport measures. Section 7 presents application examples for a variety of use cases. They serve as orientation for territories eager to develop scenario-based action plans for low carbon transport. This guideline closes with some final comments in section 8.

2. Methodological framework

A number of parameters, which are unique for each system, determine transport-related emissions. Becker et al. (2009) suggest five parameters as influencing factors: number of people, number of trips, trip length, occupancy, and emission factor. Such a comprehensive approach makes it possible to capture a wide range of reactions and effects caused by systems changes. Equation (1) shows the influencing factors on CO_2 emissions from transport activities. Table 1 gives a description of all parameters.

$$\mathbf{CO_2 = Pers \times \frac{Trips}{Pers} \times \sum_{m} mode\ share \times \frac{Pass - km}{Trip_m} \times \frac{Veh - km}{Pass - km} \times \frac{CO_2}{Veh - km}} \qquad (1)$$

Table 1: Explanation of the parameters in Equation (1)

$\mathbf{CO_2}$	**Total transport-related CO_2 emissions within a defined system** There are two common approaches for system classification: Residence principle and territory principle (European Union, 2015). The former considers all emissions caused by the residents or companies of a given territory, regardless of where the emissions are generated. The latter considers all emissions generated within a given territory, regardless of who is causing the emissions. Equation (1) is also suitable for calculating emissions generated by a location or on a relation. The length of the observation period needs to be specified for each emission calculation.
$\mathbf{Pers}$	**Number of persons within a defined system** Depending on the chosen system, this variable might refer to the number of inhabitants within a territory, the number of employees at a company, the number of travelers on a certain origin-destination relation or any other group of people.
$\mathbf{\frac{Trips}{Pers}}$	**Number of trips per person within a certain time period** This variable describes the mobility level of the group of persons considered. One trip refers to the movement from an origin to a destination, where the return trip counts as a separate trip. The trip rate depends on a variety of sociodemographic characteristics.
$\mathbf{mode\ share}$	**Percentage of trips travelled with mode m** The share of mode m multiplied by the total number of trips yields the absolute number of trips with mode m. The original formula by Becker et al. (2009) refers to motorized trips only and does not include the mode share. For integrity reasons however, it is recommended to list all modes and sum up the individual results,

even if certain modes can be considered emission-free. It is important to note that trip length, occupancy, and emission factor vary per transport mode.

$\frac{\mathbf{Pass-km}}{\mathbf{Trip_m}}$

Average distance travelled with mode m on a single trip
Since non-motorized trips tend to be much shorter than motorized trips, it is important to differentiate between modes. CO_2-emitting motorized modes add more to the overall number of passenger-kilometers travelled than non-motorized modes with zero emissions. Using an average trip length for all modes rather than the average trip length per mode will result in underestimation of CO_2 emissions.

$\frac{\mathbf{Veh-km}}{\mathbf{Pass-km}}$

Number of vehicle-kilometers per passenger-kilometer
This variable represents the inverse of the vehicle occupancy rate, which corresponds to the number of people sharing a vehicle. The occupancy rate depends on the number of seats available in a vehicle and the percentage of occupied seats.

$\frac{\mathbf{CO_2}}{\mathbf{Veh-km}}$

CO_2 emitted by transport mode m over one kilometer
The emission factor in Equation (1) only considers local end energy consumption due to vehicle operation. This approach neglects emissions caused by energy exploitation and transport, the manufacturing process, infrastructure construction etc. Local emissions depend on the vehicle’s fuel consumption and vary according to vehicle type and weight, traffic state, driving speed or style, and other factors. The average emission factor for a certain mode can either be estimated or determined in more detail based on fleet composition. Emission factors for public transport are regularly given in CO_2 per passenger-kilometer, assuming a certain occupancy rate.

The product of the number of persons, the number of motorized trips per person, the distance per motorized trip and the inverse of vehicle occupancy corresponds to the number of vehicle-kilometers traveled. The total number of vehicle-kilometers travelled within a defined system might be known from traffic counts or models. In this case, a simplified formula as shown in Equation (2) can be used to calculate CO_2 emissions.

$$\mathbf{CO_2 = Veh - km} \times \frac{\mathbf{CO_2}}{\mathbf{Veh-km}} \quad (2)$$

Equation (2) requires less data, but disguises the variety of underlying influencing factors. For this reason, it is preferable to refer to Equation (1) in order to assess low carbon options. Equation (1) allows the calculation of CO_2 emissions within a given spatiotemporal system, the identification of potential measures for reducing emissions, as well as a comprehensive estimation of measure impacts. The following three-step approach is suggested for developing low CO_2 scenarios:

1: Baseline The starting point of a low carbon future is to picture and understand the status quo. It involves a calculation of the CO_2 emissions before the beginning of the scenario building process. The baseline helps to identify the scale of change required to achieve emission reduction targets. It serves as a reference for the scenarios to be developed and the emission reductions achieved. The impacts of measure packages on the parameters in Equation (1) should lower emissions compared to the baseline. Quantification of the baseline needs to build upon thorough analysis of the territory. In case certain data cannot be collected, stakeholders may use reasonable assumptions based on their own knowledge and refer to the sample input data in section 5 of this guideline.

2: Levers Each of the parameters in Equation (1) is a lever for reducing emissions: Population decline, less motorized trips, a decrease in travel distances, increased occupancies, and lower emission factors will all reduce the amount of CO_2 emitted. With reference to the baseline, local knowledge, pre-defined objectives, and benchmarks from other territories, stakeholders need to identify the levers they can or should address. Thorough data analysis helps to highlight concrete problems. The selection of suitable measures should be based on considerations of how and how much the parameters need to change. Section 6 presents exemplary measures and information about which levers they target.

3: Scenarios Scenario building is a means to depict alternative images of an uncertain future. The future is determined by internal and external elements. Trends and other external drivers of change need to be known and understood in order to incorporate them into scenarios. Internal influences can be proactively steered by the stakeholders through measures and policies. The resulting scenarios should give vivid and comprehensible impressions of potential outcomes. Scenario-based methods facilitate participation by providing a basis for strategic discussion. In addition, they can serve awareness raising purposes. Scenario building helps to identify potential pathways towards target achievement and best fitting measure packages. Scenario building involves the quantification of emission reductions, assuming a future implementation of selected measures. For this purpose, Equation (1) can be modified based on estimations of the compound impact of measure packages on each parameter. Appropriate decision-making tools can support the process of finding suitable measures and analyzing their effects. The emission results should be below the baseline and in line with reduction targets and other objectives. Wider impacts, e.g. on other environmental, social, and economic elements cannot be neglected.

The methodological framework presented in this section is transferable to any context. However, different typologies and baselines require unique solutions. Relevant stakeholders need to specify individual visions, objectives, and targets in order to be able to select best-fit measures. The following section 3 details important points to consider when applying the methodology.

3. Recommendations for a successful application of the methodology

This section presents recommendations to stakeholders willing to develop low CO_2 scenarios and action plans for their territories. The listed points are success criteria for implementing the methodology from section 2 and are based on various findings from the literature (Banister and Hickman, 2013; Hickman et al., 2009; Hickman et al., 2011; Hickman et al., 2012; Karg et al., 2012; Wulfhorst et al., 2012; Banister et al., 2011; Chapman, 2007; Schwanen et al., 2011; Litman and Burwell, 2006; Wegener, 1996).

1. Common Vision

A vision is a desired image of the future. It is as an overarching goal, uniting a number of more specific objectives. The vision pre-defined within the ASTUS project relates to low carbon mobility in the Alpine Space. Territories may refine this vision or define their own. However, it is crucial that all stakeholders strive towards a common vision to ensure complementary action. Such a common vision can be achieved via different pathways and to a different extent, concretized in scenarios. These need to be debated in qualitative discussion rounds, involving all relevant stakeholders (see recommendation 3).

2. Clear objectives and targets

Suitable policy packages for low carbon scenarios require a clear definition of objectives. A set of specific objectives conceptualizes the desired vision of a territory's future. Within the ASTUS project, each pilot site has produced a roadmap based on their individual problems, needs, and objectives. Objectives are constituted as measurable targets, highlighting the scale of change required compared to the baseline. Emission reduction targets should be ambitious, but realistic. Concrete objectives and targets enable identification of measures that are capable of bringing about the desired CO_2 savings (see recommendation 5). Objectives specify the levers that can or should be primarily targeted (see section 2). Since sustainability encompasses far more than just greenhouse gas emissions, other environmental, economic, or social objectives can be defined and considered during the development of scenarios and action plans.

3. Stakeholder engagement

Changes are enabled by a participatory process at all levels of decision-making. This process might involve authorities, politicians, planners, businesses, organizations, associations, institutions, and citizens. The reasonable extent of involvement needs to be decided depending on the specific task. Suitable participation formats include workshops, round tables, conferences, and public information events. Stakeholder engagement serves various purposes within the development of low carbon options and should take place at different stages of the process. First of all, stakeholders act as local experts in gathering, verifying, and modifying knowledge about the territory (see recommendation 4). Thus, stakeholder engagement contributes to gaining deep knowledge from various perspectives to get a complete picture of a territory. Local expertise is valuable with respect to identifying specific challenges and realistic pathways. Such an approach is important in order to develop clear objectives and ambitious targets (see recommendation 2) and identify priorities related to carbon-reduced mobility. Strategic discussions are key to selecting effective measures that are able to achieve the desired effects on travel behavior when implemented. Public participation might not always be beneficial due to a lack of expertise. However, information and awareness raising is crucial, as citizens can reduce transport-related emissions by changing their personal mobility behavior, provided that adequate framework conditions are given. A proper communication strategy may assist in encouraging breaks in habits. Awareness is not only important to influence travel behavior, but also to initiate the required governance processes. In order to effectively join forces, one actor needs to take the lead in developing low CO_2 scenarios. Potential tasks include the identification of stakeholders to involve in the process, organization and moderation of events, data fusion and analysis, as well as presentation and preparation of draft measures as a basis for further discussion. Finally, local power in encouraging major trend-breaks is naturally limited. Stakeholders are encouraged to cooperate with neighboring territories in order to induce substantial change.

4. Knowledge about the territory

Territories differ with respect to a number of features, including size, spatial typology, transport supply, territorial structure, decision-making processes in place, as well as citizens' needs, preferences, and requirements. Each specific context requires unique strategies and measures. Therefore, excellent knowledge of a territory's characteristics is key for successfully implementing the approach described in section 2. An extensive analysis of the available data should be at the start of developing low CO_2 scenarios for daily travel. The scope needs to be clearly defined beforehand. Such analysis will help to generate a realistic baseline, identify current problems and weaknesses, and highlight potential pathways towards achieving a low carbon future. Future development is not only determined by planned measures within a territory, but also subject to external influences, e.g. demographic trends, economic development, mobility trends, changes in travel demand, and technological innovation. If a population decline is predicted, total emissions will automatically decline. In that case, the municipality needs to make sure that emissions per capita decrease. Thus, relevant internal, but also external elements need to be identified in order to develop tailor-made policy packages. The information gathered with the support of relevant stakeholders (see recommendation 3) is a prerequisite for the definition of objectives and targets (see recommendation 2) as well as the selection of feasible and effective measures (see recommendation 5). Thus, it is the basis for finding low CO_2 options that match both the territorial context and the individual expectations.

5. Effective and feasible measures

A major challenge in measure development is finding a compromise between effectiveness and feasibility. Measures should contribute towards goal attainment (see recommendation 2), but also respect limitations, e.g. related to financial or human resources. Fields of action need to be selected based on local knowledge and stakeholder discussions. Inspiration for concrete measures might come from section 6 of this guideline or other best practice examples from comparable territories. Measures should be prioritized according to how well they match the objectives and contribute towards target achievement, but also based on what is possible and desirable. Different combinations of measures create a variety of scenarios, where interaction and mutual reinforcement of measures might result in positive or negative synergies. Therefore, proper coordination and integration of individual measures needs to be ensured in order to achieve the desired multiplication effects. This especially applies to restrictive measures, which might raise acceptance issues, but will most likely create positive synergies with incentive measures. A combination of short-term, long-term, soft, hard, incentive, and restrictive measures represents the most promising strategy towards a low carbon future. Measure packages with a limited scope or single focus will have lower benefits, not only related to CO_2 emissions, but also other fields of sustainable development (see D.T1.2.2 Methodology evaluating the global impacts of mobility in Alpine Space).

6. Suitable implementation strategy

Moving from the scenario-based design to the implementation of measures is challenging. A coherent strategy, conceptualized in an action plan, is required to achieve previously defined objectives and targets (see recommendation 2). An action plan details steps or activities needed for the realization of measures. The definition of effective and feasible measures (see recommendation 5) is a basic requirement for successful implementation. Each project or measure package needs to have a responsible person or party clearly assigned. In case of limited resources, certain measures can be selected for prioritized implementation, based on their expected impact and the realization effort. Accompanying information and communication initiatives might help to improve awareness and acceptance among the persons affected. Monitoring and control mechanisms are crucial in order to evaluate the change induced and adapt the selected measure packages, if necessary. Monitoring and control processes require a pre-defined schedule based on the various implementation horizons of long-term, mid-term, and short-term measures. Additionally, indicators and corresponding thresholds need to be defined and checked regularly. If the measure packages turn out to be insufficient, measures can be added, changed or intensified to induce visible changes.

4. Transnational tool CO_{2L}

4.1. Overview

The methodological approach described in this guideline will profit from the support of suitable tools. Tools may help to define a baseline, identify options for intervention, and highlight the emission reduction potential. Thus, they provide support for the development of scenarios, strategies, and action plans. Additionally, tools might be a valuable contribution to awareness raising.

Three files that support the implementation of the methodology outlined in section 2 supplement this guideline. The files are further on referred to as CO_{2L}, a transnational tool for low CO_2 scenario building. Its main purpose is to facilitate the baseline definition and quantification of the impacts of measure packages. Table 2 outlines the contents of each file.

Table 2: Overview of the contents of the CO_{2L}

CO2L_Calculation.xlsx	The calculation sheet can be used to quantify emissions for both the baseline and a set of scenarios. For more details see section 4.2.
CO2L_Data.xlsx	The file provides sample input data for calculating CO_2 emissions in different contexts. For more details see section 5.
CO2L_Measures.xlsx	The file contains a number of potential measures for low CO_2 scenario building. For more details see section 6.

4.2. Calculation sheet

The calculation sheet is the centerpiece of the CO_{2L}. Users are able to insert data for a specific territory, location or relation in order to compare baselines and scenarios. The default version of the excel file consists of two tabs: “Interface” and “Graph”.

The “Interface” tab provides two sections. The section on the left contains the data for the baseline calculation. The section on the right contains the data for the scenario calculation. Users can enter specific values for each of the parameters in Equation (1). For an explanation of the parameters, see Table 1. Figure 1 presents an exemplary baseline section. All elements of the section are explained in Table 2.

Baseline

Total Emissions	1	637,8	tons of CO2
Persons	2	137421	
Trips / Person	3	3,4	

4	5 **Mode Share**	6 **Trips / person**	7 **Passenger-km / Trip**	8 **Vehicle-km / Passenger-km**	9 **grams of CO2 / Vehicle-km**
Foot	26%	0,884	1,4	1	0
Bicycle	7%	0,238	3,4	1	0
Car	56%	1,904	16	0,8	180
Public transport	11%	0,374	8	0,1	850
Other	0%	0	0	1	0
Total	100%	3,4	10,442		

Figure 1: Example for the section “Baseline” in CO2L_Calculation.xlsx

Table 3: Explanation of the input data of CO2L_Calculation.xlsx

1	This result box shows the total emissions in tons of CO_2. The emissions are calculated based on the input data in the other boxes. No direct entries are intended here. In case of smaller systems, users may change the formula to calculate emissions in kilograms of CO_2.
2	Users should insert the number of persons considered here. Depending on the system, this could be the number of inhabitants, employees, passengers etc.
3	The trip rate for the group inserted in [2] within the relevant time period shall be added here. Examples might be three trips per person per day or two trips per employee per workday.
4	The lines below [4] represent all transport modes available. The default modes are “Foot”, “Bicycle”, “Car” and “Public transport”. The line “Other” can be used to add another mode. Users may insert more lines if required, but they should make sure that the formula in [1] correctly references the emissions caused by each transport mode.
5	This column holds the modal split. The sum of all mode shares needs to equal 100 %.
6	The number of trips per person and mode is calculated based on the total number of trips per person in [3] and the mode share in [5]. No direct entries are intended here. The sum indicated in the bottom line equals the total number of trips per person in [3].
7	Users should add the average trip length per mode in this column. Trip lengths of non-motorized modes are naturally shorter than trip lengths of motorized modes.

An average trip length is calculated in the bottom line based on the mode share in [5] and the trip length per mode in [7].

8 This column holds the number of vehicle-km per passenger-km or the inverse of the vehicle occupancy. For example, if an average of 1.5 people share a car, the value entered here should be 0.67.

9 An emission factor in grams of CO_2 per vehicle-km is required for each mode. If the emission factor is given in grams of CO_2 per passenger-km, an assumption for the occupancy is already included. In this case, users should insert the emission factor in grams of CO_2 per passenger-km in [9] and fill in the value 1 in [8].

The structure of the section "Scenario" is the same as the structure of the section "Baseline". By default, the scenario section references the input values from the baseline section. These references should be overwritten within the scenario building process. Users may add, delete or change elements of the file CO2L_Calculation.xlsx. However, they should carefully check links, references, and formulas. If values for some parameters are unknown, user can retrieve sample input data from CO2L_Data.xlsx (see section 5).

The "Graph" tab shows the total emissions of the baseline and scenario as a bar diagram. The visualization enables quick comparison between the two calculations.

5. Input data for the baseline calculation

The baseline, which quantifies current CO_2 emissions, represents the starting point for scenario development. However, before setting a baseline, the system needs to be clearly defined with respect to spatial, temporal, and thematic boundaries. Identification of relevant stakeholders and thorough analysis of the territory need to take place at the beginning of the scenario building process as well (see section 3).

Data availability determines the degree of accuracy for the baseline calculation. Potential sources for input data include structural data from statistical offices, local surveys and inventories, as well as existing publications, plans, and models. Some input parameters might be difficult to determine directly. In this case, input parameters may be estimated based on data from comparable territories and local knowledge, considering the main determining factors of travel behavior. Short-term (e.g. mode choice, destination choice) and long-term mobility decisions (e.g. car ownership, residential location choice) depend on land-use and infrastructural conditions, the policy framework, as well as socio-economic characteristics and personal preferences. With respect to the built environment, the main factors can be identified as: settlement size and density, diversity of urban functions, locations of activities (workplaces, shops, leisure activities), availability and quality of mobility options, design of urban space and facilities for active modes, availability of parking, network connectivity, distance to public transport, and disparities in accessibility between different modes (Vale, 2013; Banister, 2011). Institutional conditions (subsidies, taxes, fees, laws, regulations) and the population group under consideration have a major influence, and may result in different outcomes even in similar built environments.

Territories with insufficient data may refer to CO2L_data.xlsx in order to estimate their baseline. Due to the variety of influencing factors described above, territories need to consider carefully if and to what extend the data is applicable in their specific case.

6. Measures for producing low CO_2 scenarios

This section is dedicated to options for reducing transport related CO_2 emissions. The Avoid, Shift, Improve (A-S-I) approach proposed by Dalkmann et al. (2014, p. 12) is a fitting strategic framework. Avoid relates to less travel through fewer trips, shorter trips, and higher occupancy rates. Shift refers to an increase in the share of eco-friendly transport modes enabled by a decrease in the share of private motorized transport. Improve addresses a higher efficiency of the remaining motorized transport, e.g. through technological improvements. The sequence of A-S-I can be considered as the order of prioritization. The supplementary file CO2L_Measures.xlsx presents selected measures. The columns give details on each measure and are outlined in Table 4.

Table 4: Explanation of the main columns in the file Measures.xlsx

Measure	The first column contains the name of the measure.
Description	Each measure has a brief description in order to clarify its intent. Specific measure examples might be given in order to improve understanding.
Estimated impact on levers	A measure usually affects several of the parameters in Equation (1) to differing extents. An estimation of the impact on each parameter is given in the columns summarized by this heading. A negative sign represents a decrease. A positive sign represents an increase. In most cases, a decrease is the desirable impact. The number of signs corresponds to a weak, medium, or strong impact. Due to the complexity of interactions, the given direction and magnitude can only serve as orientation. Individual effects are difficult to predict and quantify, as they depend on the specific context (also see remarks at the end of this section).
Particularly suitable for	Some measures are very suitable in certain contexts. A check mark indicates that the respective measure is especially recommended for the given spatial context. However, this does not suggest that it cannot or should not be implemented in a different context as well. The columns correspond to the ASTUS region types specified in O.T1.1 A territorial alpine space typology.
Implementation	Information regarding the implementation effort provides a basis for the creation of strategies and action plans. The time horizon required to implement a measure or observe its impacts is classified into short-term, medium-term, and long-term. Financial costs are estimated as high, medium or low. The implementation effort

	depends on various influencing factors, e.g. the spatial typology, the governance processes in place, and the intensity of application. For this reason, concrete numbers cannot be given. Finally, the non-exhaustive list of actors gives an idea of who would most likely need to be involved in the implementation process.
References	The last column lists sources used for the assessment of measures, literature recommendations for further reading, as well as specific implementation examples and best practices.

Measures are bundled according to the thematic fields outlined in Table 5 (Chapman, 2007; Deutsches Institut für Urbanistik, 2011; Hickman et al., 2009; Karg et al., 2012; Schwanen et al., 2011; Wulfhorst et al., 2012). If a measure cannot be clearly allocated to one of these fields, the best-fitting category is chosen.

Table 5: Thematic categorization of measures in the file Measures.xlsx

Land use	• urban planning measures on different levels that induce land use changes to create proper conditions for low carbon transport • integration with the transport system in order to improve accessibility
Active modes	• transport planning measures promoting non-motorized modes like walking and cycling • investment in facilities in coordination with land use measures to encourage shorter trips
Public transport	• transport planning measures to improve public transport supply through infrastructural or organizational measures • network development in line with land use structure
Mobility services	• Measures supporting the diffusion of innovative mobility services and transport modes • Integration between modes in order to enhance intermodal and multimodal options
Mobility management	• Soft (organizational and communicational) measures encouraging behavioral change • awareness raising is an important supplement to other measures, as it encourages individuals to embrace the

		opportunities provided by the land use and transport system
Regulation	•	Regulatory or economic measures including enforcement to restrain carbon intensive mobility behavior
	•	Act as push measures lowering the attractiveness of the car to supplement pull measures promoting alternative modes
Policy	•	Better organization of the governance process
	•	Policies that do not fit into the previous categories, mainly encouraging research and investment in energy efficient vehicle technologies as well as adaptation of technological advances

In line with the recommendations given in section 3, some important points regarding the use of the file CO2L_Measures.xlsx and the development of measure packages should be highlighted:

- The measures are supposed to help local authorities to identify and implement solutions in mobility and spatial planning. The possibilities and limitations of local decision-makers' power were considered in the selection.
- A good mix and coordination of measures is key to the development of effective measure packages. Integrated land use and transport development needs to be achieved through complementary strategies. Likewise, a combination of restrictive and incentive measures will create a push and pull effect in order to shift users from the car to alternative modes.
- The list of measures cannot be considered complete or final, but should be expanded in the future to include further suitable measures.
- Each measure provides a large number of opportunities for variation and specification. In order to ensure transnational applicability, the measure descriptions are quite loose. The ideas need to be concretized and adapted for each specific context.
- The focus with respect to the evaluation of measure impacts is on transport related CO_2 emissions. However, each measure will have wider effects, which might be in line or in conflict with other sustainability goals. For more information, please refer to D.T1.2.2 Methodology evaluating the global impacts of mobility in Alpine Space.
- Impacts on the parameters in Equation (1) will differ depending on the specific territorial context, both spatial and socio-demographic. The intensity of application and the cumulative effects generated by measures implemented in parallel are

deciding factors as well. Even though reactions to measures will be different, comparable projects in other territories can serve as a reference.

- Sensitivity analysis might help to understand the consequences of potential variations in measure impacts. The scenarios would be based on different assumptions regarding the magnitude of change in the parameter values, e.g. best guess, optimistic, and pessimistic. The different CO_2-related outcomes need to be compared with each other and with the pre-defined targets in order to develop appropriate strategies and action plans.

7. Exemplary storylines

The methodological framework introduced in section 2 can be applied within different spatial, temporal, political, and cultural contexts. This section presents three specific application examples. The exemplary storylines serve as orientation and inspiration for stakeholders willing to develop low CO_2 scenarios for their own territories. The chosen examples vary in scope and data availability in order to highlight the flexibility of the approach.

The availability of a complete dataset allows the detailed calculation of CO_2 emissions for the baseline and the scenarios (see exemplary storyline in 7.2). However, numerical data for all parameters in Equation (1) is not imperative for the scenario building process. If such data is not available, it is still possible to quantify the change induced (see exemplary storyline 7.1) or estimate the relative emission reductions achievable (see exemplary storyline 7.3).

7.1. Bus rapid transit for a region bordering on a metropolitan core

Description of the scope

This storyline is situated in a region bordering on a metropolitan core. Suburban railway lines provide public transport connections towards the center. A recently introduced bus rapid transit line with a route length of 30 kilometers serves tangential connections between major municipalities.

The responsible public transport service provider wants to estimate the bus line's potential for saving CO_2 emissions. Most citizens have a positive opinion about public transport despite high car ownership and use in the region. Good public transport service quality, increasing car ownership costs and shared mobility options might encourage more public transport use in the future.

Scenario building process

The total amount of CO_2 emissions produced on the considered link cannot be determined quantitatively due to indistinct system boundaries and lack of data. Since the public transport service provider is interested in saved emissions rather than total emissions, the baseline is considered to be zero. A positive deviation from the baseline corresponds to an increase in emissions. A negative deviation from the baseline corresponds to a decrease in emissions. The emission savings due to the bus rapid transit line correspond to the reductions in vehicle-km travelled by car. For this reason, the simplified calculation approach using Equation (2) is chosen. The achievable mode shift is estimated based on a survey conducted after one year of operation. About 3.600 people are using the bus per week. The demand on weekdays is more than double the demand on Saturdays (no service on Sundays). 450 people or 12.5 % of current users switched from the car to the bus.

Scenario: Increased attractiveness of bus rapid transit

Marketing campaigns or external trends and drivers might contribute to a further increase in public transport ridership. Considering Equation (2), CO_2 emissions from the bus rapid transit service will only change if the supply and thus the bus mileage changes. However, a route extension or more frequent services are not planned. Therefore, the change in emissions is equivalent to the change in car mileage. In order to calculate the CO_2 savings, the number of people switching from the car to the bus needs to be estimated. Based on the survey results, the public transport service provider estimates that within the next two years, 50 travelers will switch from the car to the bus on average per day for Monday through Friday. Another 15 travelers are expected to switch on Saturdays. This results in 265 persons per week changing their mode choice from car to bus on a one-way trip. Figure 2 presents the weekly emission savings due to the reduction in vehicle-km travelled by car.

Scenario					
Total Emissions	-0,68	tons of CO2			
Persons	-265				
Trips / Person	1				
	Mode Share	**Trips / person**	**Passenger-km / Trip**	**Vehicle-km / Passenger-km**	**grams of CO2 / Vehicle-km**
Car	100%	1,0	21,285	1,00	120,4
Total	100%	1	21,285		

Figure 2: Emissions for scenario 7.1

The average trip length is known from the survey. The emission factor is given in grams of CO_2 per passenger-km. Hence, the parameter vehicle-km per passenger-km is equal to 1 (see also Table 3). With the expected changes in mode share as described above, the average savings will be 0.68 tons of CO_2 per week. The emission reductions might seem small, but it should be noted that the scenario is limited to a single measure on a single link. The overall yearly savings add up to more than 35 tons, which corresponds to more than 130 kilograms per person. Other positive impacts on sustainability should not be neglected, e.g. improved mobility options, affordable travel and less congestion. CO_2 emissions from bus rapid transit were not considered in this scenario. Future service improvements resulting in an increase in bus mileage should be included in the CO_2 balance.

7.2. Sustainable commuting for a research campus

Description of the scope

This storyline gives an example of how to produce location-based scenarios. These are relevant for a number of traffic-generating institutions, e.g. companies, shopping centers or event locations. The institution chosen in this example is a research campus located at the edge of a medium size city. About 3.800 employees and 9.000 students visit the campus on a regular basis. Due to the peripheral location, a vast number of parking facilities and a lack of attractive alternatives, the mode share of the car is high.

Within the framework of a new sustainability campaign, the directors of the research campus want to reduce its CO_2 footprint. Further objectives include a reduction in parking pressure, better accessibility and mobility options and an overall increase in attractiveness. A mobility concept consisting of short- and medium-term measures will be designed to avoid and shift car travel. A number of surveys and participation formats will help to identify the best fitting measure package.

Scenario building process

The following approach was chosen to develop measures and build scenarios:

- The process started with a kick-off workshop. Campus representatives were invited to discuss the main challenges and form a working group to accompany the project.
- The first meeting of the working group was dedicated to the preparation of the data collection in order to identify the framework conditions and increase the knowledge about the situation on campus.
- The data collection included a car parking survey, an online survey and a bike parking survey. The online survey includes questions to employees and students about their mobility behavior, their motives and opinions as well as suggestions for improvement. It represents the most important data source.
- The findings from the data collection were discussed during the second meeting of the working group. First measure suggestions and a concept for a larger participation workshop were developed.
- The participation workshop was open to all employees and students on campus. The aim was to consolidate the preliminary findings and discuss the measure suggestions.
- The third meeting of the working group was used to consolidate the measure packages and start the scenario building. The results of the data collection, workshops and discussions served as input for the development of two measure packages, which were assessed with respect to their CO_2 impacts.

This storyline is an example for complete data availability, where only few assumptions are necessary. CO_2 emissions for the baseline and the scenarios can be quantified based on the survey data. Due to major behavioral differences, emissions are calculated separately for employees and students. Figure 3 presents input data and results for the CO_2 emissions generated on one average workday.

Baseline: Employees					
Total Emissions	19,73	tons of CO2			
Persons	3.800				
Trips / Person	1,83				
	Mode Share	**Trips / person**	**Passenger-km / Trip**	**Vehicle-km / Passenger-km**	**grams of CO2 / Vehicle-km**
Foot	5%	0,09	1,87	1,00	0,00
Bicycle	24%	0,44	3,95	1,00	0,00
Car	55%	1,01	26,21	0,97	175,00
Motorcycle	1%	0,01	11,54	1,00	93,99
Public transport	15%	0,27	39,63	1,00	62,77
Total	100%	1,83	21,45		

Baseline: Students					
Total Emissions	30,95	tons of CO2			
Persons	9.000				
Trips / Person	1,66				
	Mode Share	**Trips / person**	**Passenger-km / Trip**	**Vehicle-km / Passenger-km**	**grams of CO2 / Vehicle-km**
Foot	10%	0,16	1,55	1,00	0,00
Bicycle	32%	0,54	3,06	1,00	0,00
Car	34%	0,57	26,26	0,95	175,00
Motorcycle	1%	0,01	19,81	1,00	93,99
Public transport	23%	0,38	39,38	1,00	62,77
Total	100%	1,66	19,34		

Figure 3: Emissions for baseline 7.2

The trip rate is below two, since not all students and employees are on campus every day. Exact occupancy rates in public transport are unknown. Therefore, an average emission factor in grams of CO_2 per passenger-km is used. The total emissions caused by employees and students on an average workday sum up to 50.68 tons of CO_2.

The low rate of carpooling is identified as a potential lever. Only about 2 % of the campus visitors are car poolers. In addition, the low attractiveness of public transport seems to be a main issue. The campus is not well connected to the surrounding municipalities or the train station located in the city center. A shift from private car to other modes, especially public transport, is considered an important strategy. Carpooling might be effective in rural areas where public transport improvements are not really an option.

Scenario 1: Pull measures

The first measure package consists of pull measures only. Alternative options to single driving will be promoted without restricting car use. Specific measures include an additional bus stop on campus, better connections to the train station and the introduction of a carpooling platform. Accurate assumptions about the effectiveness of these measures are possible based on the collected data, e.g. residential locations, preferences and openness towards behavioral changes. The shift from car to public transport is expected to be 2 % in the case of the employees and 3 % in the case of the students. The percentage of carpoolers is expected to rise by 5 % for both employees and students, changing the number of vehicle-km per passenger-km to 0.92 and 0.88, respectively. The results of the calculation for scenario 1 are presented in Figure 4. The total emissions sum up to 47.24 tons of CO_2 per day, which is 93 % of the baseline. The change in average trip lengths per mode caused by changes in mode choice is neglected in the scenario calculation.

Scenario 1: Employees

Total Emissions	18,57	tons of CO2			
Persons	3.800				
Trips / Person	1,83				
	Mode Share	**Trips / person**	**Passenger-km / Trip**	**Vehicle-km / Passenger-km**	**grams of CO2 / Vehicle-km**
Foot	5%	0,09	1,87	1,00	0,00
Bicycle	24%	0,44	3,95	1,00	0,00
Car	53%	0,98	26,21	0,92	175,00
Motorcycle	1%	0,01	11,54	1,00	93,99
Public transport	17%	0,30	39,63	1,00	62,77
Total	100%	1,83	21,72		

Scenario 1: Students

Total Emissions	28,67	tons of CO2			
Persons	9.000				
Trips / Person	1,66				
	Mode Share	**Trips / person**	**Passenger-km / Trip**	**Vehicle-km / Passenger-km**	**grams of CO2 / Vehicle-km**
Foot	10%	0,16	1,55	1,00	0,00
Bicycle	32%	0,54	3,06	1,00	0,00
Car	31%	0,52	26,26	0,88	175,00
Motorcycle	1%	0,01	19,81	1,00	93,99
Public transport	26%	0,43	39,38	1,00	62,77
Total	100%	1,66	19,74		

Figure 4: Emissions for scenario 7.2-1

Scenario 2: Pull measures and push measures

The second scenario is more radical in that it not only includes measures to improve public transport and increase car occupancy rates, but also includes parking restrictions. Restrictive measures make car travel less attractive and thus push people away from car use. Accompanying information campaigns are helpful to mitigate acceptance issues.

The push measures will intensify the effects of scenario 1. The car mode share is estimated to decrease by a percentage of seven in the case of the employees. 4 % of the former car drivers switch to public transport and 3 % use the bike. A larger shift is expected in case of the students, since they are less dependent than the employees. Their car share reduces by 10 %, where 6 % change to public transport and 4 % switch to the bike. The carpooling rate of both students and employees increases to 10 %, inducing a change of the vehicle-km per passenger-km to 0.85 and 0.77, respectively. Figure 5 shows the daily CO_2 emissions for scenario 2.

Scenario 2: Employees					
Total Emissions	16,37	tons of CO2			
Persons	3.800				
Trips / Person	1,83				
	Mode Share	**Trips / person**	**Passenger-km / Trip**	**Vehicle-km / Passenger-km**	**grams of CO2 / Vehicle-km**
Foot	5%	0,09	1,87	1,00	0,00
Bicycle	27%	0,50	3,95	1,00	0,00
Car	48%	0,88	26,21	0,85	175,00
Motorcycle	1%	0,01	11,54	1,00	93,99
Public transport	19%	0,34	39,63	1,00	62,77
Total	100%	1,83	21,32		

Scenario 2: Students					
Total Emissions	23,72	tons of CO2			
Persons	9.000				
Trips / Person	1,66				
	Mode Share	**Trips / person**	**Passenger-km / Trip**	**Vehicle-km / Passenger-km**	**grams of CO2 / Vehicle-km**
Foot	10%	0,16	1,55	1,00	0,00
Bicycle	36%	0,60	3,06	1,00	0,00
Car	24%	0,40	26,26	0,77	175,00
Motorcycle	1%	0,01	19,81	1,00	93,99
Public transport	29%	0,48	39,38	1,00	62,77
Total	100%	1,66	19,20		

Figure 5: Emissions for scenario 7.2-2

The total emissions are 40.09 tons of CO2 per day, which is 79 % of the baseline. The results highlight the importance of push measures to achieve considerable changes.

7.3. Low carbon mobility for a county

Description of the scope

This storyline is an example of how to build low CO_2 scenarios for an entire county. The political decision-makers of the sample county have set an objective to achieve a 25 % reduction in CO_2 emissions from transport by 2030. The county's population is expected to grow by 10 % within the same time. Innovations related to vehicle technology might support the target achievement.

Scenario building process

In order to tackle the challenge of reducing CO_2 emissions despite population growth, discussion rounds with politicians, inhabitants, and companies are held. Due to a lack of data, CO_2 emissions cannot be quantified. Therefore, the reference value of the baseline is determined to be 1 or 100%. The scenarios consider the relative change achievable by different measure packages. Figure 6 presents the initial situation.

Baseline					
Total Emissions	100%				
Persons	1				
Trips / Person	1				
	Mode Share	**Trips / person**	**Passenger-km / Trip**	**Vehicle-km / Passenger-km**	**grams of CO2 / Vehicle-km**
Foot	16%	0,16	1	1	0
Bicycle	14%	0,14	1	1	0
Car	59%	0,59	1	1	1
Public transport	11%	0,11	1	1	1
Total	100%	1			

Figure 6: Emissions for baseline 7.3

Several levers could be tackled with countywide measures. The most feasible ones are a reduction in specific vehicle emissions, a change in mode share and land use measures. Measures addressing occupancy rates are not considered. The public transport supply will be developed in line with the increasing demand due to population growth and potential mode shifts. An increase in public transport occupancy would result in a reduction of vehicle-km per passenger-km. Such development would reduce the overall CO_2 emissions, but is not considered in this storyline.

Scenario 1: Reductions in specific emissions

The first scenario focuses on an increase in the efficiency of private cars. The county aims to support the market penetration of low emission vehicles. In addition, the responsible decision-makers would like to encourage low carbon driving. Measures include the development of charging infrastructure, financial incentives, information campaigns on low carbon driving techniques and competitions for eco-driving. Overall, a 20 % improvement in vehicle efficiency is expected. Figure 7 presents the relative changes achievable in scenario 1.

Scenario 1					
Total Emissions	91%				
Persons	1,1				
Trips / Person	1				
	Mode Share	**Trips / person**	**Passenger-km / Trip**	**Vehicle-km / Passenger-km**	**grams of CO2 / Vehicle-km**
Foot	16%	0,16	1	1	0
Bicycle	14%	0,14	1	1	0
Car	59%	0,59	1	1	0,8
Public transport	11%	0,11	1	1	1
Total	100%	1			

Figure 7: Emissions for scenario 7.3-1

The emissions are 9 % below the baseline. Improved efficiency of private vehicles will compensate for additional emissions due to population growth, but is not sufficient to achieve the set target.

Scenario 2: More active travel and public transport

Scenario 2 addresses behavioral changes in order to examine the effectiveness of such a strategy compared to scenario 1. The aim is to achieve a shift in mode choice from the car to other modes by infrastructural and organizational improvements of alternative modes. Cycling measures include better cycling infrastructure, e.g. bike parking facilities, as well as the establishment of a position responsible for countywide planning, promotion, and implementation of cycling measures. The mode share of public transport increases due to bus prioritization on selected routes and more attractive pricing schemes. The public transport supply will be successively enhanced in order to improve the service and maintain the level of comfort. The occupancy rate, i.e. the parameter vehicle-km per passenger-km, remains unchanged. This will result in a larger contribution of public transport to the overall emissions. The scenario building process yields a 15 % reduction in car mode share, with 5 % switching to walking, cycling and public transport, respectively. As shown in Figure 8, the emissions in scenario 2 correspond to 94 % of the baseline.

Scenario 2

Total Emissions	94%
Persons	1,1
Trips / Person	1

	Mode Share	Trips / person	Passenger-km / Trip	Vehicle-km / Passenger-km	grams of CO2 / Vehicle-km
Foot	21%	0,21	1	1	0
Bicycle	19%	0,19	1	1	0
Car	44%	0,44	1	1	1
Public transport	16%	0,16	1	1	1
Total	100%				

Figure 8: Emissions for scenario 7.3-2

As in scenario 1, the emission reductions through the proposed measures compensate for the increase caused by population growth. However, they barely contribute to further reductions. A more comprehensive strategy seems to be required to achieve the target of a 25 % emission reduction.

Scenario 3: Integrated land use and transport measures

Scenario 3 presents a more radical solution, combining the previous scenarios and adding land use measures. A structural land use plan is introduced on county level in order to coordinate measures between municipalities. Dense development and functional mix will be promoted in coming years in order to reduce trip lengths. The effect is estimated to be a 10 % reduction in motorized trip lengths. The measures to improve vehicle efficiency are identical to the measures described in scenario 1. Again, the relative savings in grams of CO_2 per vehicle-km are estimated to be 0.8. The measures to increase the attractiveness of cycling and public transport are the same as in scenario 2 described above. 5 % will switch from car to public transport, walking and cycling each. Figure 9 shows the combined results of scenario 3.

Scenario 3					
Total Emissions	72%				
Persons	1,1				
Trips / Person	1				
	Mode Share	**Trips / person**	**Passenger-km / Trip**	**Vehicle-km / Passenger-km**	**grams of CO2 / Vehicle-km**
Foot	21%	0,21	1	1	0
Bicycle	19%	0,19	1	1	0
Car	44%	0,44	0,9	1	0,8
Public transport	16%	0,16	0,9	1	1
Total	100%				

Figure 9: Emissions for scenario 7.3-3

A combination of the vehicle efficiency measure package from scenario 1, the alternative modes measure package from scenario 2 and additional land use measures results in a 28 % reduction in CO_2 emissions compared to the baseline. Scenario 3 highlights how the set targets could be achieved in the sample county.

8. Final remarks

Stakeholders willing to develop low CO_2 scenarios, strategies, and action plans for their territories should be aware of restrictions and limitations in connection with the methodology presented in this guideline.

Data and examples provided can be a reference, but should not be copied without contemplation. Their main purpose is to serve as orientation and basis for qualitative discussions. Many ideas are transferable to a certain degree, but need to be adapted depending on the respective context to find an individual pathway towards a low carbon future.

The methodology is tailored to specifically address CO_2 emissions. However, there is a range of other impacts caused by transport activities. Likewise, measures will not only target CO_2 emissions, but also have other effects on sustainability. Wider consequences of certain measure packages should be considered in a multi-level approach, where CO_2 impacts might be only one criterion within a comprehensive impact analysis (see for example D.T1.2.2 Methodology evaluating the global impacts of mobility in Alpine Space). Such an approach ensures compatibility with other objectives when developing specific strategies and action plans for low carbon pathways.

Due to the ASTUS project's focus on daily passenger trips, the approach does not consider all transport-related CO_2 emissions. Long distance travel, air travel, and freight transport are difficult to address on a local level. More data and knowledge is available related to short and medium distance passenger transport, thus providing better opportunities for intervention by local stakeholders. However, due to their large contribution to overall transport-related emissions, long distance and freight transport should be addressed further on.

Despite some limitations, initiation of a comprehensive governance process based on this methodology represents an important step towards sustainable transport in the Alpine Space.

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