Research Programme Mobility
Full-proposal for Call 2021

Full proposals (PDF + Excel) have to be submitted by e-mail to:
energieforschung@bfe.admin.ch (subject: "Mobility Call 2021")

1 Project key data

Project title* *English*	Sustainable cHEmicaL Transport fuEls foR SwitzErlanD		
Project title* *National language*	Nachhaltige chemische Treibstoffe für die Schweiz		
Project acronym *Max. 15 characters*	SHELTERED		
Call topic addressed *Check the most important one*	☐ 1) New mobility concepts ☒ 2) Perspectives and analyses of the transport system		
Main project partner *Co-ordinator*	Institution/Company, Department:	Paul Scherrer Institut (PSI), Technology Assessment	
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Duration of the project	Months in total: 36	Expected start date: October 2021	Expected end date: September 2024
Total project costs:	CHF 562'300	**Requested funding:**	CHF 397'000
Scientific abstract* *English, publishable text, max. 150 words*	This project will evaluate the role and perspectives of sustainable chemical transportation fuels within a "net-zero" Swiss energy system. To this end, we will perform techno-economic, environmental and social life cycle assessment of a comprehensive portfolio of chemical fuels – including hydrogen, biogenic, sun-to-liquid, and power-to-gas/liquid fuels – and integrate those in a scenario-driven energy system analysis. Due to limited sustainable primary energy resources for such fuel production in Switzerland, the analysis will be performed on a global level to identify plausible sources and locations for fuel production and import pathways. The following questions will be answered: 1. Which transportation modes will have to rely (partially) on chemical fuels due to lack of direct electrification options? 2. Which of these fuels and which supply pathways are sustainable considering economic, environmental, and social criteria? 3. What is the role of these fuels in the Swiss energy system to meet the net-zero emission goals?		

* *Project title and scientific abstract have to be provided in both, English and a national language.*

Scientific abstract* *National language, publishable text, max. 150 words*	In diesem Projekt werden die Rolle und die Perspektiven nachhaltiger chemischer Treibstoffe innerhalb eines "Netto-Null"-Energiesystems der Schweiz untersucht. Zu diesem Zweck wird eine techno-ökonomische, ökologische und gesellschaftliche Lebenszyklusanalyse eines breiten Spektrums an chemischen Treibstoffen durchgeführt (inklusive Wasserstoff, biogenen Treibstoffen, Sun-to-Liquid und Power-to-Gas/Liquid-Treibstoffen), welches in eine von Szenarien getriebene Energiesystemanalyse integriert wird. Aufgrund begrenzter nachhaltiger Primärenergieressourcen für eine solche Treibstoffproduktion in der Schweiz wird die Analyse auf globaler Ebene durchgeführt, um plausible Energiequellen und Standorte für die Treibstoffproduktion sowie zugehörige Importpfade zu identifizieren. Die folgenden Fragen sollen beantwortet werden: 1. Welche Verkehrsträger werden aufgrund fehlender direkter Elektrifizierungsmöglichkeiten auf chemische Kraftstoffe angewiesen sein? 2. Welche dieser Kraftstoffe sind unter Berücksichtigung ökonomischer, ökologischer und sozialer Kriterien nachhaltig; und wie sehen ihre Versorgungswege aus? 3. Welche Rolle spielen diese Kraftstoffe im Schweizer Energiesystem insgesamt, um die Netto-Null-Emissionsziele zu erreichen?
Changes with respect to the pre-proposal, if any	This full proposal is consistent with the preceding pre-proposal.

2 Main idea and significance *(max. ½ page)*

While individual motorized passenger transport can be decarbonized using battery electric vehicles, such direct electrification is more challenging for other transport modes such as long-haul heavy-duty trucks, shipping, and aviation. These modes may have to rely on gaseous or liquid fuels with high energy densities without major breakthroughs in battery development [1]–[3]. Currently, aviation and road freight transport cause about 5 Mt [4] and 2.8 Mt [5] of Swiss Greenhouse Gas (GHG) emissions.

Alternatives to direct electrification exist: hydrogen for fuel cell electric vehicles or aircraft turbines [1], and biomass based, "sun-to-liquid", and "power-to-liquid/gas" synthetic fuels for combustion engines [6]–[8]. Production costs and whether such chemical fuels qualify as low-carbon fuels depend on their origin and production pathways, carbon intensity of electricity and feedstock supply, their costs and availability as well as CO_2 sources [9], [10]. These key parameters show high geographical variability.

Low-carbon chemical fuels need to be imported to large extents, since domestic potentials for renewable electricity generation and biomass are limited and mainly needed for defossilisation of sectors other than freight transport and aviation, as recently demonstrated by the Swiss Energy Perspectives 2050+ [11] and similar scenario analysis performed by PSI [12]. Since key factors determining sustainability of chemical fuels depend on their origin, evaluation of supply chains requires a global perspective. And since the portfolio of potential technologies on both the supply and demand side is very broad and interdependencies and potential synergies between specific options exist, a technology-rich, bottom-up scenario modelling framework is required to identify best-suited chemical fuel supply options, and to quantify their role in Switzerland's pathway to carbon neutrality by 2050.

We will combine prospective sustainability assessment of current and future chemical fuel production and supply pathways considering economic, environmental and social performance indicators with global scenario modelling, which accounts for technological progress, resource constraints, (inter)national climate policy, etc. We will answer questions like: How much chemical low-carbon fuels will be required for the Swiss transport sector? To which extent can they contribute to a reduction of Swiss GHG emissions and primary energy demand? What are sustainable domestic and foreign production and supply pathways? Answering these questions will provide decision support for Swiss energy and climate policy and the Federal Offices involved, and also for many other stakeholders.

3 Scientific context, method and objectives

3.1 Project objectives and scientific questions addressed *(max. 1 page)*

Imported and domestically produced chemical fuels for decarbonization of the Swiss transport sector (and further applications) can – depending on feedstock used, production pathways and origin – substantially differ regarding their costs, environmental and social impacts. We will evaluate the sustainability performance of chemical fuel supply and use in Switzerland by employing global and Swiss energy system models in order to answer the following research questions:

1. What are the costs, environmental burdens, and social impacts of potential low-carbon chemical fuels – domestically produced and imported – considering a wide range of production and international supply pathways to Switzerland as well as different geographical boundary conditions?
2. What are the national and international supply potentials?
3. Which of these fuels serve their primary purpose – a cost effective reduction of GHG emissions – best in which sub-sector of the Swiss transport system and potential further applications?
4. What are the most economic, environmentally and socially sound production and supply chains?
5. To which extent and at which costs will such fuels be needed and be able to contribute to achieving the goals of Swiss climate and energy policies?

3.2 State-of-the-art *(max. ½ page)*

From the technology perspective, even a generic, but consistent evaluation of the economic, environmental and social performance of potential low-carbon chemical fuels is missing. Literature only offers a fragmented foundation for sustainability assessment [6], [7], [10], [13], [14]. Also previous work of the applicants – still providing a very useful knowledge basis – has limited scope and lacks detail [2], [6], [9], [14]–[16]. All these studies suffer from shortcomings, e.g., not addressing future technology development, limitations in terms of feedstock and conversion processes, lack of transparency, etc. These shortcomings impede their direct use for feeding energy system models and decision support.

Energy system model based evaluation of the contribution of chemical transport fuels to reach Swiss climate goals with international scope and high level of detail in terms of technologies, feedstock and fuel supply pathways, and including international aviation has not been performed so far. Some of the previous work of the applicants focused on road transport and considered the international perspective in a simplified way without differentiation between different chemical fuel types and associated import pathways [17]–[19]. The two most recent and comprehensive scenario-based evaluations of transformation pathways of the Swiss energy system towards net-zero GHG emissions showed a substantial demand of partially imported chemical energy carriers, despite of excluding international aviation and the associated fuel demand in Switzerland [11], [12]. Specifically, in the recently published "Energieperspektiven 2050+" [11], domestic production as well as import of hydrogen and biomass/-fuels, and import of synthetic fuels from the MENA region is assumed, building upon an analysis for Germany [20]. Energy system based scenario assessments for Switzerland did not consider the environmental perspective beyond impacts on climate change, with one exception [21]. This analysis, however, did not address "net-zero" transformation pathways and lacks detail in terms of chemical fuels.

3.3 Approach and research method *(max. 2 pages)*

We will evaluate the economic, environmental, and social performance of a wide range of chemical fuels to be used in the Swiss transport sector with a global scope and a high geographical resolution. To this end, we will perform 1) techno-economic evaluation and 2) environmental and social Life Cycle Assessment (LCA) of a broad set of transport fuels differentiated according to location of production and import pathways to Switzerland; 3) scenario-based evaluation of the role of these fuels in a future "net-zero" Swiss energy system by employing an advanced Swiss energy system model in combination with a global model; and 4) link the technology assessment and the system modelling framework.

Techno-economic and Life Cycle Assessment will be carried out in line with established standards [22]–[24] and will explicitly take into account feedstock and resource availability on a regional basis. Prospective assessment will build upon "premise" [25], our software framework for coupling energy system models with LCA. We will extend this framework to allow for modifying the ecoinvent LCA background database [26] in line with the projections from the energy system models to be applied within this project, thereby creating a scenario-dependent, dynamic assessment.

Energy system modelling will employ the ***Global Multi-regional MARKAL*** (GMM) model – a technology-rich bottom-up model, which represents the global energy system [19]. Within the framework of this project, we will extend the model and integrate low-carbon chemical fuel production pathways, including negative emission technologies [27], [28] and assess different global climate mitigation scenarios. Technology characteristics from the techno-economic assessment will serve as input for the scenario assessment. GMM model outputs on the availability and costs of chemical fuels produced in different regions worldwide represent boundary condition for the ***Swiss TIMES Energy systems Model*** (STEM) [12], which will be used for quantifying the need for chemical fuels in Switzerland. STEM covers the whole Swiss energy system from resource supply to end use sectors through energy conversion and distribution with a long-term horizon (2010-2050). We will extend STEM by including international aviation, which allows to quantify the role of chemical fuels in the Swiss energy system and their sustainability through the proposed LCA.

The novelty of the proposed work can be summarized as follows:

- Evaluating the economic, environmental and social performance of potential low-carbon chemical transport fuels: The proposed work represents an unprecedented scope in terms of 1) primary feedstock (electricity, biomass, solar energy) considering regional potentials on a global level, 2) feedstock-to-fuel conversion pathways (power-to-liquid/-gas, sun-to-liquid, gasification, reforming, etc., including CC(U)S), 3) geographical coverage (worldwide with a regional resolution), temporal coverage (today up to 2050); and 4) the integrated assessment framework guarantees consistency.
- We employ existing global and Swiss energy systems models, which will be extended to include the entire portfolio of chemical low-carbon fuels. The global model [19] assesses availability of low-carbon chemical fuels based on regional resource potential while fulfilling global mitigation goals, thus revealing insights on plausible production pathways of chemical (and bio-)fuels from a global perspective to assess their suitability. We quantify the need for domestically produced and imported chemical fuels for Switzerland to fully decarbonise the Swiss energy system, including international aviation, for the first time.

3.4 Data *(max. ½ page)*

Technology assessment will rely on academic and grey literature, databases such as ecoinvent, exiobase, the Social Hotspots Database, the Product Social Impact LCA database, information from industry, ongoing research projects, and surveys among experts (building upon the network to be created via the advisory board). Established contacts due to past and ongoing collaborations with companies such as Synhelion and Climeworks as well as the stakeholder advisory board will be used to get access to first hand data regarding process performances and costs, and their expected development. Learning rates together with expert estimates will be applied for prospective analysis. Potentially limited data quality will be addressed by uncertainty assessment and extensive sensitivity analysis.

3.5 Targeted outcomes *(max. 1 page)*

We will generate a comprehensive and consistent set of key performance indicators (KPI) regarding the economic, environmental, and social performance of chemical fuels for Switzerland, covering a broad range of feedstock options as well as domestic and global supply pathways and taking into account expected technology development until 2050. The KPI (e.g., fuel costs, their carbon, water and resource footprint, impact on distribution effects, jobs created, etc.) enable comparing different fuels and identification of preferred options by accounting for potential co-benefits and trade-offs coming along with the reduction of GHG emissions from a life cycle perspective. We will integrate the assessed fuel supply pathways in our online LCA and LCC tool [29] and the underlying models will be hosted in an open-access repository, ensuring full transparency and reproducibility. Models will be fully parameterized, thus be open for modification and further use by third parties. Also the prospective LCA framework [25], which will be extended as part of this project, is open-access and can be used by third parties. Life cycle inventories will be available for integration into any other LCA database.

On the basis of “what-if” scenarios we will quantify the potential and availability of low-carbon chemical fuels at the global scale as well as the need for such imported low-carbon fuels to Switzerland, and assess their role in reduction of Swiss GHG emissions towards zero, including the emissions from international aviation. With a coherent assessment of global and Swiss scenarios, we identify sectors of primary interest, most promising supply pathways under a range of boundary conditions in terms of national and international climate policies, CO_2 prices, industrial policies, and resource availabilities.

4 Implementation

4.1 Work plan *(max. 1 page)*

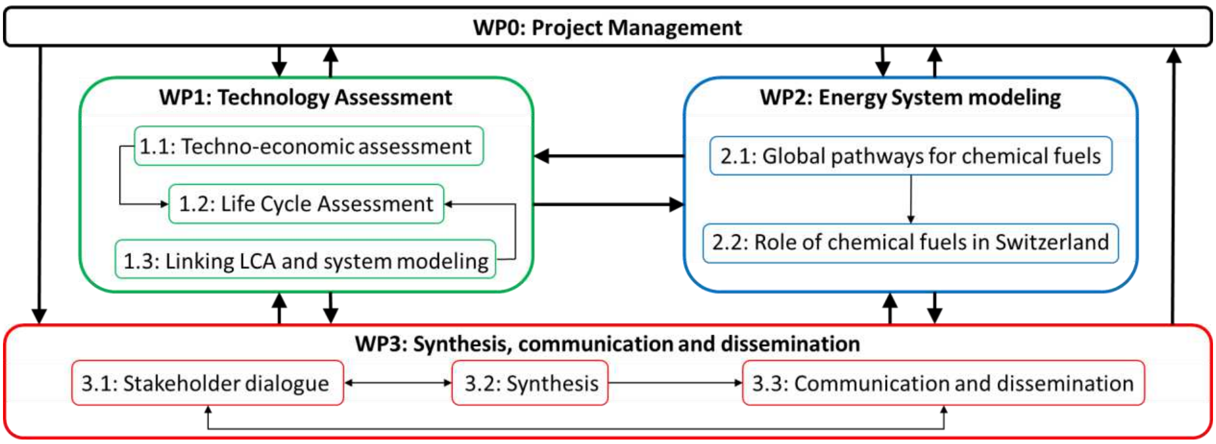
The work will be carried out in four dedicated work packages (WP), described in detail in section 4.2. Tasks will be carried out according to the project schedule visualized in the following Gantt chart, in which also deliverables (D) and milestones (MS) are indicated.

	2021	2022				2023				2024		
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
WP0: Project management	MS1											
WP1.1: Techno-economic assessment				D1.1								
WP1.2: LCA (environmental, social)										D1.2		
WP1.3: Linking LCA and system model								MS6				
WP2.1: Global model extensions				MS4								
WP2.2: Swiss model extensions							MS5					
WP2.3: Scenario assessment						D2.1					D2.2	
WP3.1: Stakeholder dialogue	MS2	MS3									MS7	
WP3.2: Project synthesis												D3.1
WP3.3: Outreach, dissemination												D3.2

MS1: Schedule for project team meetings and meetings between SFOE and PSI established; month 3.
MS2: Advisory group and meeting dates for workshops established; month 3.
MS3: Advisory board workshop #1; month 6.
MS4: Tested GMM with low-carbon chemical energy pathways; month 12.
MS5: Tested STEM with international aviation and options for imported low-carbon fuels; month 21.
MS6: Link between LCA and energy system models established; month 24.
MS7: Advisory board workshop #2; month 33.
D1.1: Technology specification report; month 12.
D1.2: Sustainability assessment. Open access scientific journal paper; month 30.
D2.1: Global supply options and pathways of low-carbon chemical fuels. Report; month 18.
D2.2: Assessment of low-carbon chemical fuels in Switzerland. Report; month 33.
D3.1: Synthesis report; month 36.
D3.2: Policy briefs; month 36.

4.2 Work packages *(max. 1 page per WP)*

The project consists of four work packages as shown in the following scheme and as detailed below:



WP0: Project management – Objective: Ensuring an efficient and effective execution of the project; lead: PSI-TAG; contributions: PSI-EEG. M1-36.

This WP will track progress and ensure effective procedures and interaction between all WP. The project manager will implement risk mitigation measures, if necessary. This WP represents the "contact point" to SFOE as funding organization and is responsible for reporting, administrative and financial issues. Quarterly meetings between the project team and SFOE will be organized. Project team meetings will take place on a regular basis to monitor progress in reaching the milestone and deliverables.

WP1: Technology Assessment – Objectives: Technology specification and sustainability assessment; lead: PSI-TAG; contributions: PSI-EEG. M1-30.

Task 1.1: Techno-economic assessment

- Sub-task 1.1.1 – Technology specification: The scope of the analysis in terms of fuels to be evaluated, primary energy carriers, their potential and availability, production locations, conversion processes, and supply chains with fuel storage and transport options will be determined. Each process in these supply chains will be specified in terms of capacity, process efficiency, loss rate, lifetime, and location to reflect regional differences. We aim at completeness in terms of feedstocks, conversion processes, fuel types, storage and transport options, and supply routes, in the sense that all potentially relevant options for supply of low-carbon chemical fuels to Switzerland will be covered, including domestic production. We aim at consensus with and within the advisory board in this context. Technology specification will be performed for 2020-2050 considering the expected development based on the system models of WP2. Parameter ranges with minima, maxima and best estimates will be established. Fuel characteristics will be specified to ensure that only perfect substitutes will directly replace fossil fuels in the analysis. Otherwise, required adaptations on the end-use side will be addressed, or fuel blends used. The outcomes of this sub-task are key to the entire project: They will serve as basis for the economic assessment (task 1.1.2) and LCA (task 1.2), and also for the extension of both the Swiss and the global energy system models in WP2.
- Sub-task 1.1.2 – Economic Assessment: This sub-task will quantify production and supply costs of chemical low-carbon fuels according to the technology specification in sub-task 1.1.1 – i.e. the levelized fuel costs ready to be used in Switzerland. In line with technology specification, cost ranges will be estimated. Geographical differences will be taken into account, e.g., in terms of feedstock and capital cost, informed by the system models developed and used in WP2.

Task 1.2: Environmental and social Life Cycle Assessment (LCA)

- Sub-task 1.2.1 – Environmental LCA: The environmental performance of chemical fuels will be evaluated based on established LCA methodology and consistently with the technology specification in task 1.1.1. ecoinvent [26] will be used as source of background LCA data for current technologies; prospective assessment will use a dynamic background employing the "premise" framework [25], extended in terms of functionality (in task 1.3) to use information from the energy system models of WP2. We will address not only impacts on climate change, but also environmental co-benefits and trade-offs such as land use, air pollutants, and biodiversity losses.
- Sub-task 1.2.2 – Social LCA: Social impacts of chemical low-carbon fuels will be evaluated from a life cycle perspective according to best scientific practices in the domain of social LCA [30]–[32] and in accordance with the technology specification of sub-task 1.1.1. Uncertainties in this context will be addressed in a semi-quantitative way performing sensitivity analysis. Geographical differences will be taken into account to the extent possible, potentially limited by data availability.

Task 1.3: Linking LCA and energy system modelling

Within this task, the existing framework for linking LCA and energy system or integrated assessment models [25] will be extended to modify the ecoinvent database building upon the scenario-dependent transformation pathways of the energy system models in WP2.

D1.1: Technology specification – report. M12.

D1.2: Sustainability assessment of chemical low-carbon fuels for Switzerland (economic, environmental, and social evaluation) – open-access scientific journal paper. M30.

WP2: Energy System modelling – Objective: Identification of global pathways for supply of low-carbon chemical fuels and their role in a carbon-neutral Swiss energy system; lead: PSI-EEG.

Tasks in this WP include extension of the Swiss and global energy system models (STEM and GMM) and their application for scenario analysis.

Task 2.1: Global pathways for low-carbon chemical fuels

We will extend the scope of the well-established Global Multiregional MARKAL (GMM) model [19] to include a comprehensive set of technological pathways for production of low carbon chemical fuels. GMM is a technology-rich, multi-region global model with a cost optimization framework [18]. The technology characterization from WP1 will be the basis for this task complemented by literature data on regional resource potentials. With this model extension, we will assess global climate mitigation scenarios with different mitigation goals. This enables us to identify possible sources of low-carbon chemical fuels from the global perspective, as well as the competition on these fuels of various consumers across different sectors and regions worldwide. These supply pathways will be used as the boundary conditions for the LCA in WP1 and via cost-supply curves as import options in the Swiss mitigation scenarios in Task 2.2.

Task 2.2: Role of low-carbon chemical fuels in Switzerland

This task is to assess the role of chemical fuels in the Swiss energy system to meet the climate neutrality by 2050 set out in the Swiss Energy perspective [11]. STEM is a technology-rich model for Switzerland with high temporal resolution. The model has been extensively used for assessment of net-zero emission pathways [12], [17]. However, in those scenarios, origins of imported zero carbon fuels are not traceable, like an many other studies [11], [20], and international aviation is not included. Thus, we will extend the scope of STEM to include international aviation and enhance the domestic production and supply of imported low-carbon fuels. The technology characterization for production of chemical fuel will be based on the technology assessment from WP1 – consistent with the global model. Again, the global scenarios from task 2.1 serve as the basis for origin of imported fuels.

D2.1: Global production pathways of low carbon fuels – report. M18

D2.2: Net-zero pathways for Switzerland and role of imported chemical fuels – report. M33

WP3: Synthesis, communication and dissemination – Objectives: Synthesizing key project outcomes and their dissemination; lead: PSI-TAG; contributions: PSI-EEG.

Task 3.1: Dialogue with stakeholders

Dialogue with stakeholders will be organized via an advisory board to be established by month three. Stakeholders to be invited will cover a broad range of interests (section 4.6). At least two workshops will be organized (M6, M33). The purpose of the dialogue is many-fold: a) collecting stakeholder perspectives regarding goal, scope and methodology and considering these throughout the project in WP1 and WP2; b) receiving feedback on outcomes and its consideration in the project synthesis (task 3.2); c) using stakeholders as source of information, e.g., regarding process performance and costs, for WP1 and WP2; d) using stakeholders as multipliers in communication and dissemination (task 3.3).

Task 3.2: Synthesis of project outcomes

Findings of WP1 and WP2 will be integrated in a synthesis report. Key messages will be compiled and summarized in policy briefs. A draft of the synthesis report will be shared with the advisory board before the second workshop. Feedback will be taken into account when finalizing this report. Synthesis report and policy briefs will serve as basis for communication and dissemination.

Task 3.3: Communication and dissemination

Project outcomes will be disseminated in target-group specific ways during the entire project. We will use PSI's website, twitter and linkedin channels. Project results will be disseminated at two scientific conferences. Scientific papers will be submitted to high-impact journals and published open-access. Policy briefs – aiming at a non-scientific audience – will be shared with popular media to create impact. Stakeholders being part of the advisory board will be used for their dissemination as well.

D3.1: Synthesis report. M36.

D3.2: Policy briefs. M36.

4.3 Project management, risk assessment and organisation *(max. ½ page)*

The project will be carried out by two groups at PSI: Technology Assessment (TAG) and Energy Economics (EEG). These two groups are both part of PSI's Laboratory for Energy Systems Analysis and collaborate on a daily basis. Christian Bauer (TAG), senior scientist, will act as project manager, thus be responsible for an efficient and effective execution of the work plan. He will also provide his scientific expertise and supervise a PhD student to be hired for SHELTERED. This PhD student will provide the core contributions of TAG in terms of analysis and research. Tom Kober, EEG group leader, will act as project manager deputy. The core of the work from EEG will be performed by a scientist.

In order to establish a risk mitigation plan, risks associated with the different tasks and objectives have been identified; their degree of Probability (low - L; medium - M; high - H), and the severity in terms of Impact have been assessed. Risk mitigation will be implemented as described in the table below.

Risk	WP	Probability	Impact	Risk mitigation measure
Long-term absence of project manager	0	L	H	Deputy takes over
Delayed recruiting	1,2	M	M	Current staff starts project work
Key staff leaving during project	all	M	H	Depending on timing: recruitment of new staff / available staff takes over
Worsening of the pandemic situation	all	M	L	Research is entirely desk-based; structures for effective remote work are in place
Lack of specific data	1,2	L	H	Increasing uncertainty to be addressed by extensive sensitivity analysis
Any issues with energy system models	1,2	L	H	Low risk due to use of established models; cost-neutral project extension as fall-back

4.4 Project partners *(max. ½ page per partner)*

Main project partner *PSI – Technology Assessment / Christian Bauer*	Expertise:	The Technology Assessment group (TAG) has an extensive track record in sustainability assessment of transport fuels and vehicle technologies as well as in linking LCA and energy system models [2], [6], [9], [14]–[16], [21], [25], [26], [33]. Christian Bauer, acting as principal investigator (PI) and manager of this project, has recently been PSI's PI within the SCCER Heat and Electricity Storage and the ERA-NET ACT project ELEGANCY. He is currently PI and work package leader within the H2020 project ROBINSON and member of the board of the ecoinvent association.
	Role in project:	TAG will lead this project and carry out the technology specification of the fuel production and supply pathways in terms of technical characteristics, geography-specific boundary conditions, and expected development until 2050. This specification will serve as basis for sustainability assessment of individual chemical fuel production and supply chains, the core of WP1. The technology specification will also represent a key input to the energy system modelling activities in WP2. TAG will also lead project synthesis, communication and dissemination activities (WP3).

Project Partner #2	Institution/Company, Department:	PSI – Energy Economics group (EEG)
	Postal address:	Forschungsstrasse 111, CH-5232 Villigen PSI
	Name, First Name:	Kober, Tom; Kannan, Ramachandran
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	E-mail:	tom.kober@psi.ch; kannan.ramachandran@psi.ch
	Expertise:	The Energy Economics group (EEG) has extensive experience in analysing energy policy strategies towards net-zero carbon energy systems [12]. EEG has participated in several projects funded by SFOE, Swiss Electric Research, the European Commission and third party organisations and has acted as leading partner within the SCCER Joint Activity Scenarios and Modelling. The group continuously updates and maintains the GMM and STEM models and has an extensive track record [12], [17]–[19], [21], [34].
	Role in project:	EEG will perform scenario-driven and energy system based analysis of the role of low-carbon chemical fuels within the Swiss energy system – applying and linking the Swiss-specific model STEM and the global model GMM as core activities in WP2. Further, EEG will contribute to project management, project synthesis, and communication and dissemination (WP3).

4.5 Link with ongoing projects *(max. ½ page)*

Environmental assessment of synthetic aviation fuels (Funding source: FOCA): PSI-TAG performs environmental LCA of selected synthetic aviation fuels. The evaluations are based on current technologies and representative or average processes and boundary conditions. The outcomes will provide a basis for the much more sophisticated analysis in SHELTERED. Duration: 11/2020 – 08/2021.

Environmental LCA of road transport vehicles (Funding source: FEON): PSI-TAG establishes new life cycle inventories for road transport vehicles and associated fuel chains for the UVEK LCI database and “mobitool”. Generic “power-to-liquid” fuels will be included. Some outcomes of this project will provide a basis for the much more sophisticated analysis in SHELTERED. Duration: 11/2020 – 07/2021.

Ariadne (Funding source: German Federal Ministry of Education and Research): The Ariadne project investigates transformation pathways towards net-zero GHG emissions for Germany. PSI-TAG carries out environmental LCA of potential low-carbon technologies in the German energy system. Further, algorithms for linking LCA and integrated assessment models will be developed. SHELTERED will be co-funded by Ariadne. Duration: 08/2020 – 05/2023.

SWEET – SURE (Funding source: SFOE): In the project SURE, transformation pathways of the Swiss energy system towards decarbonisation are analysed in detail with focus on sustainability and resilience aspects. In this project, PSI carries out the techno-economic modelling of the Swiss energy sector as well as LCA of key decarbonisation technologies. The global perspective and international supply pathways for chemical fuels are not part of energy-economic modelling and LCA in SURE, while they are in SHELTERED. Synergies of SHELTERED and SURE refer to common scenario definition and the exchange of technology databases and scenario assumptions. Duration 05/2021 – 04/2027

Synfuel initiative (Funding source: ETH board): Advanced processes for synthetic aviation fuel production based on renewable resources will be developed. PSI-TAG performs environmental and economic evaluation. PSI-EEG carries out system model-based assessment of these synfuels within the overall energy system. SHELTERED will be co-funded by this initiative. Duration: 01/2021 – 12/2023.

4.6 Monitoring *(max. ½ page)*

An advisory board consisting of experts and stakeholders in the field from Swiss federal offices, industry, associations, international bodies, NGOs, and academics will be established. We aim for an international composition of the advisory board covering a broad range of interests. Each Federal office potentially interested in this project (SFOE, FOEN, FOCA, SECO, FEDRO) will be invited to nominate at least one representative. Further stakeholders to be invited include swisscleantech, Siemens, sunfire, Synhelion, Climeworks, TCS, VCS, ASTAG, City of Zurich, SBB, Swiss, Zurich airport, Pilatus, WWF, Greenpeace, Energiestiftung, ETHZ, EPFL, University of St. Gallen, ZHAW, University of Geneva, IEA, PIK Potsdam, and University College London.

At least two workshops with the advisory board will be carried out; to be organized in hybrid form allowing attendance in person or virtually to be flexible regarding the further development of the current pandemic as well as international participation as such. This stakeholder group will be updated on project progress on a regular basis and be invited to provide feedback on methodology, approach and outcomes. We will also use this stakeholder group as multiplier for dissemination and communication.

5 Impact

5.1 Expected impacts *(max. 1 page)*

Our analysis and the associated communication and dissemination activities will represent decision support for both policy and industry: The identification of most promising low-carbon chemical fuels as well as their preferred production and supply routes can be considered as key contribution to implement a sustainable long-term strategy towards zero GHG emissions in sectors, which are hard to directly electrify [9]. The quantification of the contribution of chemical fuels to the reduction of Swiss GHG emissions from a system perspective while evaluating potential environmental, economic and social co-benefits and trade-offs in parallel will guarantee relevance of the project outcomes from a general societal perspective and their uptake by a broad range of stakeholders. Investigating different boundary conditions and developing trajectories regarding technology, costs, climate policy, etc. will allow for estimation of the robustness of the outcomes and identification of “no-regret” policies.

5.2 Dissemination and exploitation of results *(max. 1 page)*

We will address different target groups with our dissemination activities: 1) the research community by publishing open-access articles and models in high-level, peer-reviewed scientific journals; 2) high-level decision makers in policy, (inter)national bodies, industry, NGOs, and associations by releasing policy briefs; and, 3) the interested public by integration of the sustainability assessment of chemical vehicle fuels into our LCA web-tool [29]. In addition, our stakeholder workshops aim at establishing a dialogue among parties involved, which is supposed to continue beyond the lifetime of this project.

We will use PSI’s communication channels (website, twitter and linkedin) for dissemination of project outcomes to reach this broad range of stakeholders and interest groups. We will also use some of the stakeholders we aim to include in the advisory board as multipliers and communicate our findings through specific bodies such as the IPHE hydrogen production analysis task force, or the IEA HEV task force on LCA of electric vehicles, in which the applicants participate.

In line with previous technology assessment activities in the area of sustainable mobility, we will aim at full transparency and provide models together with input data used for LCA and economic evaluation of fuel chains in an open-access online repository and integrated in our LCA web-tool [29]; environmental life cycle inventories will be available for integration in databases like the UVEK LCI database or ecoinvent. We expect substantial impact in both the scientific and public domains, since recent experience has shown that making research accessible in transparent and at the same time “non-scientific ways” is key for uptake of research results by society and building trust. Moreover, the open access character of the technology assessment will maximize the added value of our work for the scientific community and trigger (inter)national collaboration in further research activities.

6 Finances

Costs are declared in the Excel file “Finance_sheet_SHELTERED.xls”, submitted with this proposal.

6.1 Cross-financing

Has an inquiry or an official application for further financial contributions been made to another federal funding institution (Innosuisse, SNSF, FOEN, FOT, FEDRO, SwissEnergy, etc.) or has any other third party funding been applied for (Cantons, Industry, Associations) for ~~the current project or~~ a related project? Also indicate if such applications are still planned.

☒ **Yes** ☐ **No**

If yes, give the date of submission, the name of the funding institution and the decision and/or evaluation received:

14.10.2020 – Federal Office of Civil Aviation (FOCA) – related project: Environmental LCA of synthetic aviation fuels. Decision: funding was granted. Content: see section 4.5.

7.1.2021 – Federal Office for the Environment (FOEN); related project: LCA of vehicles. Decision: funding was granted. Content: see section 4.5.

11.01.2021 – Federal Office of Energy (SFOE); related project: SWEET – SURE. Decision: funding was granted. Content: see section 4.5.

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