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sweet swiss energy research for the energy transition

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Abbreviations

GCC = Grand Composite Curve

HP = Heat Pump

MEA = Monoethanolamine

NET = Negative Emission Technology

PA = Pinch Analysis

PI = Process Integration

SGHP = Steam Generating Heat Pump

SSP = Source Sink Profile

HTHP = High-Temperature Heat Pump

Summary

The mission of the DeCarbCH team is to help stakeholders from the public and private sector to decarbonize the supply of heating and cooling. We do this by focusing on key aspects like (1) future thermal network concepts, (2) the integration of thermal storage to manage peak loads and to improve the seasonal balancing of the energy system, (3) the optimal integration of renewable energy sources and storages into industrial processes and (4) by identifying and developing options to generate negative CO2 emissions. We also aim at better integrating existing technologies as solar thermal or high-temperature heat pumps, and at developing new opportunities as geothermal energy.

DeCarbCH started mid of 2021 and is now fully operational. On 25/26 April 2022 the team met in person for our first networking conference. We used the opportunity to listen to our implementation partners, the representatives of cities, administration and industrial companies. This helped us to better understand their challenges and to fine-tune our research plans if needed. The work of the first year is documented in the present report. In the following we summarize just a few highlights:

Thermal grids allow to distribute renewable energy and to recycle waste heat (e.g., from cooling or industrial processes) for heating applications. DeCarbCH develops technical solutions for future thermal grids and grid-connected applications like thermal storages. It develops a solid understanding of new thermal grid concepts and its underlying control algorithms to form a base for future energy planning. An initial step was an extensive literature review to determine common characteristics of thermal networks that allow the definition of representative network archetypes. These include anergy grids connected to waste-water treatment plants, standard medium-temperature grids fed by lake water heat pumps, and grids connected to biomass or fossil CHP plants. Also thermal storage concepts are being studied in detail, e.g. borehole thermal energy storage (BTES).

Pinch Analysis (PA) is a key tool to identify (1) the absolute energy saving potential of an overall system and (2) the measures to best exploit it, e.g. heat recovery, optimization of the energy supply, use of energy conversion systems like heat pumps, thermal energy storage, and optimal integration of renewables. In the first year a database has been created that includes the energetic and economic parameters of these PAs, as well as the proposed measures. Based on this database we started constructing exemplary energy profiles that represent the energetic demands and excess heat at company level for various production classes in Switzerland. This will especially allow to better understand at which temperature level process heat is required by Swiss industry, possibly paving the way for a larger share of industrial high-temperature heat pumps. Exemplary energy profiles will also provide a quick “energetic fingerprint” of an industrial company. This is important for scoping studies to encourage industrial companies to transition toward renewables. It will allow practitioners to scale the exemplar energy profile according to their production size to explore the economical energy efficiency measures and their potential renewables integration opportunities.

A central activity in DeCarbCH is the collaboration with cities to help them to overcome the issues of decarbonizing the heating demand. Good relationships have been established with several large cities as Geneva, Lausanne and Zurich. Priorities have been defined and are now worked out by the research teams, the main ones being the reduction of temperature in district heating networks, the replacement of fossil peaking units and the integration of storage, both to manage demand peaks and to improve the seasonal balancing of supply and demand. This work will have to lead in a few years to P&D projects with interested partners.

Negative emission technologies will be required to meet the Swiss goal of net-zero greenhouse-gas emissions by 2050. This was found by the team of Energieperspektiven 2050+ and is confirmed by the latest energy system modelling done in DeCarbCH. We also see that the major source of negative emissions are the waste-to-energy plants and wood-fired combined heat and power plants. The challenge is the large thermal energy demand of the separation process – energy that may not be available to heating networks anymore. We therefore focused on the optimum heat integration options for the case of a wood plant. This will help plant owners to take economic decisions.

An important part of our work is non-technical in nature. It focuses on the social, economic and legal aspects of the energy transition. The aim is to gain an overview of the actors involved in the heating / cooling sector in Switzerland. This provides an empirical and conceptual basis for the elaboration of new business models and policy measures. The empirical basis used in the first reporting period consists of the 17 semi-structured interviews with decision-makers in Swiss manufacturing firms, stakeholder workshops, interviews and scoping meetings with different actors of the Swiss energy sector (utilities, city administration, planners, energy consultants, technology providers, manufacturing companies, entrepreneurs), as well as secondary data such as open datasets, policy documents and company documentation. Finally, our legal research contributes to clarifying the legal barriers to future renewable cooling and heating solutions: It clarifies the law that governs district heating systems, it analyses the legal requirements in the planning process, the permits and the operation and use of district heating systems, and it gives an overview of the current state of the legal rules.

Résumé

La mission de l'équipe DeCarbCH est d'aider les acteurs des secteurs public et privé à décarboniser l'approvisionnement en chauffage et en refroidissement. Pour ce faire, nous nous concentrons sur des aspects clés tels que (1) les futurs concepts de réseaux thermiques, (2) l'intégration du stockage thermique pour gérer les pics de charge et améliorer l'équilibrage saisonnier du système énergétique, (3) l'intégration optimale des sources d'énergie renouvelables et du stockage dans les processus industriels et (4) l'identification et le développement d'options pour générer des émissions négatives de CO2. Nous visons également à mieux intégrer les technologies existantes comme le solaire thermique ou les pompes à chaleur haute température, et à développer de nouvelles opportunités comme la géothermie.

Le projet DeCarbCH a démarré au milieu de l'année 2021 et est désormais pleinement opérationnel. Les 25 et 26 avril 2022, l'équipe s'est réunie en personne pour notre première conférence de mise en réseau. Nous avons profité de l'occasion pour écouter nos partenaires de mise en œuvre, les représentants des villes, des administrations et des entreprises industrielles. Cela nous a permis de mieux comprendre leurs défis et d'affiner nos plans de recherche si nécessaire. Le travail de la première année est documenté dans le présent rapport. Nous n'en résumons ici que quelques points saillants :

Les réseaux thermiques permettent de distribuer de l'énergie renouvelable et de recycler la chaleur perdue (par exemple, à partir de processus de refroidissement ou industriels) pour des applications de chauffage. DeCarbCH développe des solutions techniques pour les futurs réseaux thermiques et les applications connectées au réseau, comme les accumulateurs thermiques. Il développe une solide compréhension des nouveaux concepts de réseaux thermiques et de leurs algorithmes de contrôle sous-jacents, afin de constituer une base pour la planification énergétique future. La première étape a consisté

en une analyse documentaire approfondie afin de déterminer les caractéristiques communes des réseaux thermiques qui permettent de définir des archétypes de réseaux représentatifs. Il s'agit notamment des réseaux anergie connectés à des stations d'épuration des eaux usées, des réseaux standard à moyenne température alimentés par des pompes à chaleur à eau de lac, et des réseaux connectés à des centrales de cogénération à biomasse ou à combustible fossile. Les concepts de stockage thermique sont également étudiés en détail, par exemple le stockage d'énergie thermique par forage (BTES).

L'analyse Pinch (PA) est un outil clé pour identifier (1) le potentiel absolu d'économie d'énergie d'un système global et (2) les mesures pour l'exploiter au mieux, par exemple la récupération de chaleur, l'optimisation de l'approvisionnement en énergie, l'utilisation de systèmes de conversion d'énergie comme les pompes à chaleur, le stockage d'énergie thermique et l'intégration optimale des énergies renouvelables. La première année, une base de données a été créée, comprenant les paramètres énergétiques et économiques de ces PA, ainsi que les mesures proposées. Sur la base de cette base, nous avons commencé à construire des profils énergétiques exemplaires qui représentent les demandes énergétiques et l'excès de chaleur au niveau de l'entreprise pour différentes classes de production en Suisse. Cela permettra notamment de mieux comprendre à quel niveau de température l'industrie suisse a besoin de chaleur industrielle, ouvrant éventuellement la voie à une plus grande part de pompes à chaleur industrielles à haute température. Les profils énergétiques exemplaires fourniront également une "empreinte énergétique" rapide d'une entreprise industrielle. Cet aspect est important pour les études d'opportunité visant à encourager les entreprises industrielles à se tourner vers les énergies renouvelables. Il permettra aux praticiens d'adapter le profil énergétique exemplaire à la taille de leur production afin d'explorer les mesures d'efficacité énergétique les plus économiques et les possibilités d'intégration des énergies renouvelables.

Une activité centrale de DeCarbCH est la collaboration avec les villes pour les aider à surmonter les problèmes de décarbonisation de la demande de chauffage. De bonnes relations ont été établies avec plusieurs grandes villes comme Genève, Lausanne et Zurich. Les priorités ont été définies et sont maintenant élaborées par les équipes de recherche, les principales étant la réduction de la température dans les réseaux de chauffage urbain, le remplacement des unités de pointe fossiles et l'intégration du stockage, à la fois pour gérer les pics de demande et pour améliorer l'équilibrage saisonnier de l'offre et de la demande. Ces travaux devront déboucher dans quelques années sur des projets de P&D avec des partenaires intéressés.

Des technologies à émissions négatives seront nécessaires pour atteindre l'objectif suisse de zéro émission nette de gaz à effet de serre d'ici 2050. C'est ce qu'a constaté l'équipe d'Energieperspektiven 2050+ et ce que confirme la dernière modélisation du système énergétique réalisée dans DeCarbCH. Nous constatons également que les principales sources d'émissions négatives sont les installations de valorisation énergétique des déchets et les centrales de cogénération au bois. Le défi réside dans l'importante demande d'énergie thermique du processus de séparation - une énergie qui n'est peut-être plus disponible pour les réseaux de chauffage. Nous nous sommes donc concentrés sur les options optimales d'intégration de la chaleur dans le cas d'une usine de bois. Cela aidera les propriétaires d'usines à prendre des décisions économiques.

Une part importante de notre travail est de nature non technique. Elle se concentre sur les aspects sociaux, économiques et juridiques de la transition énergétique. L'objectif est d'obtenir une vue d'ensemble des acteurs impliqués dans le secteur du chauffage et du refroidissement en Suisse. Cela fournit une base empirique et conceptuelle pour l'élaboration de nouveaux modèles économiques et de mesures politiques. La base empirique utilisée dans la première période de rapport consiste en 17 entretiens semi-structurés avec des décideurs dans des entreprises manufacturières suisses, des ateliers de parties prenantes, des entretiens et des réunions de cadrage avec différents acteurs du secteur énergétique suisse (services publics, administration municipale, planificateurs, consultants en énergie, fournisseurs de technologie, entreprises manufacturières, entrepreneurs), ainsi que des données secondaires telles que des ensembles de données ouvertes, des documents politiques et de la documentation d'entreprise. Enfin, notre recherche juridique contribue à clarifier les obstacles juridiques aux futures solutions de refroidissement et de chauffage renouvelables : Elle clarifie la loi qui régit les systèmes de chauffage urbain, elle analyse les exigences juridiques dans le processus de planification, les permis et l'exploitation et l'utilisation des systèmes de chauffage urbain, et elle donne un aperçu de l'état actuel des règles juridiques.

Zusammenfassung

Die Mission des DeCarbCH-Teams ist, Akteure aus dem öffentlichen und privaten Sektor bei der Dekarbonisierung der Wärme- und Kälteversorgung zu unterstützen. Dabei konzentrieren wir uns auf Schlüsselaspekte wie (1) zukünftige Wärmenetzkonzepte, (2) die Integration von Wärmespeichern zur Bewältigung von Lastspitzen und zur Verbesserung des saisonalen Ausgleichs im Energiesystem, (3) die optimale Integration erneuerbarer Energiequellen und -speicher in industrielle Prozesse und (4) die Ermittlung und Entwicklung von Optionen zur Erzeugung negativer CO_2-Emissionen. Außerdem wollen wir bestehende Technologien wie Solarthermie oder Hochtemperaturwärmepumpen besser integrieren und neue Möglichkeiten wie Geothermie entwickeln.

DeCarbCH ist Mitte 2021 gestartet und ist nun voll einsatzfähig. Am 25./26. April 2022 traf sich das Team persönlich zu unserer ersten Netzwerkkonferenz. Wir nutzten die Gelegenheit, um unseren Umsetzungspartnern, den Vertretern von Städten, Verwaltungen und Industrieunternehmen, zuzuhören. Dies half uns, ihre Herausforderungen besser zu verstehen und unsere Forschungspläne wenn nötig anzupassen. Die Arbeit des ersten Jahres ist im vorliegenden Bericht dokumentiert. Im Folgenden fassen wir nur einige Highlights zusammen:

Thermische Netze ermöglichen die Verteilung erneuerbarer Energien und die Verwendung von Abwärme (z. B. aus Kühl- oder Industrieprozessen) für Heizzwecke. DeCarbCH entwickelt technische Lösungen für zukünftige Wärmenetze und netzgekoppelte Anwendungen wie Wärmespeicher. Es entwickelt ein solides Verständnis neuer Wärmenetzkonzepte und der zugrundeliegenden Regelungsalgorithmen, um eine Grundlage für die zukünftige Energieplanung zu schaffen. Ein erster Schritt war eine umfassende Literaturrecherche, um gemeinsame Merkmale von Wärmenetzen zu ermitteln, die die Definition repräsentativer Netzarchetypen ermöglichen. Dazu gehören Anergienetze, die an Kläranlagen angeschlossen sind, Standard-Mitteltemperaturnetze, die von Seewasser-Wärmepumpen gespeist werden, und Netze, die an Biomasse- oder fossile KWK-Anlagen angeschlossen sind. Auch thermische Speicherkonzepte werden eingehend untersucht, z. B. thermische Bohrlochspeicher (BTES).

Die Pinch-Analyse (PA) ist ein zentrales Instrument zur Ermittlung (1) des absoluten Energieeinsparpotenzials eines Gesamtsystems und (2) der Maßnahmen, mit denen dieses am besten ausgeschöpft werden kann, z. B. Wärmerückgewinnung, Optimierung der Energieversorgung, Einsatz von Energieumwandlungssystemen wie Wärmepumpen, thermische Energiespeicher und optimale

Integration erneuerbarer Energien. Im ersten Jahr wurde eine Datenbank erstellt, die die energetischen und wirtschaftlichen Parameter dieser PAs sowie die vorgeschlagenen Maßnahmen enthält. Basierend auf dieser Datenbank haben wir begonnen, exemplarische Energieprofile zu erstellen, die den Energiebedarf und den Wärmeüberschuss auf Unternehmensebene für verschiedene Produktionsklassen in der Schweiz darstellen. Dies wird es insbesondere ermöglichen, besser zu verstehen, auf welchem Temperaturniveau Prozesswärme in der Schweizer Industrie benötigt wird, was möglicherweise den Weg für einen grösseren Anteil industrieller Hochtemperatur-Wärmepumpen ebnet. Exemplarische Energieprofile werden auch einen schnellen "energetischen Fingerabdruck" eines Industrieunternehmens liefern. Dies ist wichtig für Scoping-Studien, um Industrieunternehmen zur Umstellung auf erneuerbare Energien zu bewegen. Es wird den Praktikern ermöglichen, das beispielhafte Energieprofil entsprechend ihrer Produktionsgröße zu skalieren, um die wirtschaftlichen Energieeffizienzmaßnahmen und ihre potenziellen Möglichkeiten zur Integration erneuerbarer Energien zu untersuchen.

Eine zentrale Aktivität im Rahmen von DeCarbCH ist die Zusammenarbeit mit Städten, um sie bei der Bewältigung der Probleme der Dekarbonisierung des Wärmebedarfs zu unterstützen. Mit mehreren großen Städten wie Genf, Lausanne und Zürich wurden bereits gute Beziehungen aufgebaut. Die Prioritäten wurden festgelegt und werden nun von den Forschungsteams ausgearbeitet. Die wichtigsten sind die Senkung der Temperatur in den Fernwärmenetzen, der Ersatz von fossilen Spitzenaggregaten und die Integration von Speichern, um Nachfragespitzen zu bewältigen und den saisonalen Ausgleich von Angebot und Nachfrage zu verbessern. Diese Arbeiten werden in einigen Jahren zu P&D-Projekten mit interessierten Partnern führen müssen.

Zur Erreichung des Schweizer Ziels, bis 2050 keine Treibhausgasemissionen mehr zu verursachen, werden Technologien für negative Emissionen benötigt. Dies wurde vom Team der Energieperspektiven 2050+ festgestellt und wird durch die neueste Modellierung des Energiesystems in DeCarbCH bestätigt. Wir sehen auch, dass die größte Quelle negativer Emissionen die Müllverbrennungsanlagen und die holzbefeuerten Kraft-Wärme-Kopplungsanlagen sind. Die Herausforderung ist der große Bedarf an thermischer Energie für den Abtrennungsprozess - Energie, die den Wärmenetzen möglicherweise nicht mehr zur Verfügung steht. Wir haben uns daher auf die optimalen Möglichkeiten der Wärmeintegration für den Fall einer Holzanlage konzentriert. Dies wird Anlagenbesitzern helfen, wirtschaftlich fundierte Entscheidungen zu treffen.

Ein wichtiger Teil unserer Arbeit ist nicht-technischer Natur. Er konzentriert sich auf die sozialen, wirtschaftlichen und rechtlichen Aspekte der Energiewende. Ziel ist es, einen Überblick über die Akteure des Wärme-/Kältesektors in der Schweiz zu gewinnen. Damit wird eine empirische und konzeptionelle Grundlage für die Ausarbeitung neuer Geschäftsmodelle und politischer Massnahmen geschaffen. Die empirische Grundlage, die im ersten Berichtszeitraum verwendet wurde, besteht aus 17 halbstrukturierten Interviews mit Entscheidungsträgern in Schweizer Industrieunternehmen, Stakeholder-Workshops, Interviews und Scoping-Treffen mit verschiedenen Akteuren des Schweizer Energiesektors (Versorgungsunternehmen, Stadtverwaltung, Planer, Energieberater, Technologieanbieter, Industrieunternehmen, Unternehmer) sowie Sekundärdaten wie offene Datensätze, politische Dokumente und Unternehmensdokumente. Schließlich tragen unsere juristischen Untersuchungen dazu bei, die rechtlichen Hindernisse für künftige erneuerbare Kühl- und Heizlösungen zu klären: Sie klären das für Fernwärmesysteme geltende Recht, analysieren die rechtlichen Anforderungen an den Planungsprozess, die Genehmigungen sowie den Betrieb und die Nutzung von Fernwärmesystemen und eben einen Überblick über den aktuellen Stand der rechtlichen Regelungen.

Riassunto

La missione del team DeCarbCH è di aiutare gli stakeholder del settore pubblico e privato a decarbonizzare la fornitura di riscaldamento e raffreddamento. Lo facciamo concentrandoci su aspetti chiave come (1) i futuri concetti di rete termiche, (2) l'integrazione dell'stoccaggio termico per gestire i picchi di carico e migliorare il bilanciamento stagionale del sistema energetico, (3) l'integrazione ottimale delle fonti di energia rinnovabili e degli stoccaggi nei processi industriali e (4) identificando e sviluppando opzioni per generare emissioni negative di CO2. Puntiamo inoltre a integrare meglio le tecnologie esistenti, come il solare termico o le pompe di calore ad alta temperatura, e a sviluppare nuove opportunità come l'energia geotermica.

DeCarbCH è stato avviato a metà del 2021 ed è ora pienamente operativo. Il 25/26 aprile 2022 il team si è riunito di persona per la prima conferenza di networking. Abbiamo colto l'occasione per ascoltare i nostri partner di implementazione, i rappresentanti di città, amministrazioni e aziende industriali. Questo ci ha aiutato a comprendere meglio le loro sfide e a perfezionare i nostri piani di ricerca, se necessario. Il lavoro del primo anno è documentato nel presente rapporto. Di seguito ne riassumiamo solo alcuni punti salienti:

Le reti termiche consentono di distribuire energia rinnovabile e di riciclare il calore di scarto (ad esempio, dal raffreddamento o dai processi industriali) per applicazioni di riscaldamento. DeCarbCH sviluppa soluzioni tecniche per le future reti termiche e per le applicazioni connesse alla rete, come gli stoccaggi termici. Sviluppa una solida comprensione dei nuovi concetti di rete termica e degli algoritmi di controllo sottostanti, per costituire una base per la pianificazione energetica futura. Un primo passo è stata un'ampia revisione della letteratura per determinare le caratteristiche comuni delle reti termiche che consentono di definire archetipi di rete rappresentativi. Questi includono le reti anergiche collegate agli impianti di trattamento delle acque reflue, le reti standard a media temperatura alimentate da pompe di calore ad acqua di lago e le reti collegate a impianti di cogenerazione a biomassa o fossili. Si stanno studiando in dettaglio anche i concetti di stoccaggio termico, ad esempio lo stooccaggio di energia termica in fori (BTES).

La Pinch Analysis (PA) è uno strumento chiave per identificare (1) il potenziale di risparmio energetico assoluto di un sistema complessivo e (2) le misure per sfruttarlo al meglio, ad esempio il recupero di calore, l'ottimizzazione dell'approvvigionamento energetico, l'uso di sistemi di conversione energetica come le pompe di calore, l'accumulo di energia termica e l'integrazione ottimale delle fonti rinnovabili. Nel primo anno è stato creato un database che comprende i parametri energetici ed economici di questi PA, nonché le misure proposte. Sulla base di questo database abbiamo iniziato a costruire profili energetici esemplari che rappresentano la domanda energetica e il calore in eccesso a livello aziendale per diverse classi di produzione in Svizzera. Ciò consentirà in particolare di capire meglio a quale livello di temperatura è richiesto il calore di processo dall'industria svizzera, aprendo eventualmente la strada a una maggiore quota di pompe di calore industriali ad alta temperatura. I profili energetici esemplificativi forniranno anche una rapida "impronta energetica" di un'azienda industriale. Ciò è importante per gli studi di scoping volti a incoraggiare le aziende industriali a passare alle energie rinnovabili. Permetterà ai professionisti di scalare il profilo energetico esemplare in base alle dimensioni della loro produzione per esplorare le misure di efficienza energetica più economiche e le potenziali opportunità di integrazione delle rinnovabili.

Un'attività centrale di DeCarbCH è la collaborazione con le città per aiutarle a superare i problemi di decarbonizzazione della domanda di riscaldamento. Sono stati stabiliti buoni rapporti con diverse grandi

città come Ginevra, Losanna e Zurigo. Le priorità sono state definite e vengono ora elaborate dai gruppi di ricerca; le principali sono la riduzione della temperatura nelle reti di teleriscaldamento, la sostituzione delle unità di picco fossili e l'integrazione dello stoccaggio, sia per gestire i picchi di domanda che per migliorare il bilanciamento stagionale di domanda e offerta. Questo lavoro dovrà portare in pochi anni a progetti di P&D con partner interessati.

Per raggiungere l'obiettivo svizzero di azzerare le emissioni di gas serra entro il 2050, saranno necessarie tecnologie a emissioni negative. Questo dato è stato rilevato dal team di Energieperspektiven 2050+ ed è confermato dall'ultima modellizzazione del sistema energetico effettuata in DeCarbCH. Vediamo anche che la principale fonte di emissioni negative sono gli impianti di termovalorizzazione dei rifiuti e gli impianti di cogenerazione a legna. La sfida è rappresentata dalla grande richiesta di energia termica del processo di separazione, energia che potrebbe non essere più disponibile per le reti di riscaldamento. Ci siamo quindi concentrati sulle opzioni ottimali di integrazione del calore nel caso di un impianto a legna. Questo aiuterà i proprietari degli impianti a prendere decisioni economiche.

Una parte importante del nostro lavoro è di natura non tecnica. Si concentra sugli aspetti sociali, economici e legali della transizione energetica. L'obiettivo è quello di ottenere una panoramica degli attori coinvolti nel settore del riscaldamento/raffreddamento in Svizzera. Ciò fornisce una base empirica e concettuale per l'elaborazione di nuovi modelli di business e misure politiche. La base empirica utilizzata nel primo periodo di rendicontazione è costituita da 17 interviste semi-strutturate con i responsabili delle aziende manifatturiere svizzere, workshop con gli stakeholder, interviste e incontri di approfondimento con i diversi attori del settore energetico svizzero (aziende di servizi pubblici, amministrazione comunale, pianificatori, consulenti energetici, fornitori di tecnologia, aziende manifatturiere, imprenditori), nonché da dati secondari quali dataset aperti, documenti politici e documentazione aziendale. Infine, la nostra ricerca giuridica contribuisce a chiarire gli ostacoli legali alle future soluzioni di raffreddamento e riscaldamento rinnovabili: Chiarisce la legge che regola i sistemi di teleriscaldamento, analizza i requisiti legali nel processo di pianificazione, le autorizzazioni, il funzionamento e l'utilizzo dei sistemi di teleriscaldamento e fornisce una panoramica dello stato attuale delle norme giuridiche.

1 Consortium's objectives

The DeCarbCH project addresses the colossal challenge of decarbonisation of heating and cooling in Switzerland within three decades and it prepares the grounds for negative CO2 emissions. The overall objective of the project (with the ultimate target of net zero emissions) is to facilitate, speed up and de-risk the implementation of renewables for heating and cooling in the residential sector (for various scales and degrees of urbanization) as well as for the service and the industry sector

- by providing guidance on which combinations of technologies to implement where, to which extent and when

- by developing, piloting and demonstrating combinations of commercially viable technologies thereof, consequently helping to drive down the cost of renewable heating and cooling in all sectors

- by conducting model-based analyses that support planning, inter alia by the development of scenarios representing the supply, distribution and demand of renewable heating and cooling services

- by quantifying the value of both renewable heating and cooling as well as of negative CO2 emissions

- by providing evidence-based guidance on how to enable the implementation of renewable heating and cooling by policies and by legal measures as well as by engaging with the relevant actors and ensuring the necessary level of acceptance.

The DeCarbCH project focusses on three main components, i.e. i) advanced renewable energy and transformation technologies, ii) thermal grids (for heating and cooling) and iii) energy storage. For these, we establish optimal combinations (in technical, economic and environmental terms) as well as necessary and desirable conditions for their implementation.

2 Status of the work packages

WP n°	WP title	Status *(X as appropriate)*					
		Previously completed: Final report published on ARAMIS	Completed during the reporting period (RP): Final report submitted to be reviewed	Ongoing: Progress & next steps to be reviewed	Starting during the next RP: First steps to be reviewed	New: Proposal and budget to be reviewed and approved; notes to be reviewed	Starting after the next RP: not yet reviewed
G1	Consortium management			X			
G2	KTT (Knowledge and Technology Transfer)			X			
01	Thermal Energy System Modelling at the Mesoscale: developing spatially resolved decarbonization pathways for thermal energy			X			
02	Understanding legal and socio-economic integration of clean heat and cooling solutions			X			
03	Technologies, design, and operation of thermal grids for future energy planning			X			
04	Energy demand profiles of industry and the potential for renewables integration and negative emissions			X			
05	Combination of renewables, heat transformation and storage for medium and high temperature heating as well as cooling			X			
06	Case Study 1, City of Zurich			X			
07	Case studies Romandie: strategies and potentials of temperature reduction on existing district heating networks			X			

08	Scenario and modelling, pathways, tool development, policy recommendations						X
09	Legal and socio-economic integration of proposed solutions						X
10	A multi-criteria assessment suite to support decision-making of renewables integration in industry						X
11	Lab scale thermal-grid-indifferent testing of a prototype for heating and cooling						X
12	Generation of negative CO_2 emissions			X			
XX	Placeholder work package to reserve resources for exploring emerging technologies and solutions						X
PD1	Real Transformation of a specific area in Zurich						X
PD2	Increase in utilization of waste heat from incineration plant / Reduction of carbon emissions						X
PD3	Enabling implementation of renewables for industrial heating and cooling / Demonstrating enabled renewable heating and cooling (solutions) in industry						X
PD4	Renewable energy cube providing carbon-neutral heating and cooling for industry and service sector						X
PD5	Demonstration of negative emission technology						X

3 Work performed and results of ongoing work packages

3.1 WP 1: Thermal Energy System Modelling (ESM) at the Mesoscale: developing spatially resolved decarbonization pathways for thermal energy

Title	Thermal Energy System Modelling (ESM) at the Mesoscale: developing spatially resolved decarbonization pathways for thermal energy			
Actual start	*04/2021*		**End**	*03/2025*
TRL range	**Starting at**	*X*	**Ending at**	*X*
WP leader	*Jonathan Chambers, UNIGE*			
Members and coop. partners	*Jonathan Chambers, UNIGE-EE, Jonathan.chambers@unige.ch* *Gianfranco Guidati, ETHZ, gguidati@ethz.ch* *Martin Neugebauer, OST-SPF,* martin.neugebauer@ost.ch			
Objectives				
The overall objective of this work package is to support energy planning at local, cantonal and national level. This WP hence aims to substantially improve the state of the art of techno-economic thermal-ESM by i) integrating a range of (novel) technologies and data sources, ii) applying state-of-the-art modelling theory & methods with meso-scale spatio-temporal resolution, iii) linking thermal ESM with full system ESMs. This will be used to explore scenarios and generate thermal energy system transition pathways.				

Work performed and results

New context:

The Russian invasion of Ukraine has put new emphasis on the need to stop using fossil fuels. For heat this means the elimination of oil and gas heating in buildings and industry. It has spurred higher renewable share and efficiency improvement targets at the European level which are likely to have spill over effects in Switzerland, although Switzerland has not yet made a political statement in this direction at the Federal level.

Among the most likely short term effects with bearing on the work of this Work Package are the increase in market for heat pumps and district heating systems, which are likely to affect their costs. There will also likely be adjustments in priorities with respect to energy independence, which may increase pressure for using local energy resources. Changing costs and policy landscape may give additional impetus to emerging technologies like seasonal energy storage, however there are very large unknowns in this area.

A significant challenge from this changing context, in addition to the initial findings (see Task 1.2) is that it become significantly harder to model the technology adoption decisions that will be made, and therefore to produce robust energy transition pathway scenarios.

Task 1.1: Characterization of thermal energy system elements

This task aimed to build a database of existing and upcoming data required for energy system modelling as well as providing a common point of reference across different DeCarbCH work packages. In fact, this concept was in large part adopted into the SWEET-CROSS project and the definition of common datasets and development of an online data set registry was merged with the CROSS activities, with initial development of the shared database concept being conducted as a joint task between CROSS and DeCarbCH WP1.

For the first deliverable D1.1.1, datasets on heating and cooling demands in buildings were published in open access data archives and linked to the CROSS site. Communication around the project was conducted to encourage sharing and re-use of datasets, including at the CISBAT 2021 conference with an associated paper[1].

The initial CROSS data site is now online (https://sweet-cross.ch/data/) and further work is being done to increase its impact, for example through improving dataset indexing and search functions. A key finding during the initial development stages was that there exist sufficient data archival services for open data, so the main add value is in improving the discoverability and metadata. This motivated working towards a subject-specific database which could act if needed as a data repository but mainly could act as an index linking to datasets published in other places. Through this indexing nature even confidential datasets can be referenced while only reporting the public portion of their metadata and enabling researchers to send requests to the respective administrators. The intention is to assist researchers in finding the right data sets for their needs, ensuring that datasets have sufficient documentation, and encouraging re-use of datasets thereby achieved shared starting points.

On the basis of this work, one policy recommendation is that there needs to be policy-level support for data indexing and harmonisation across research and for knowledge transfer. Building and supporting such indexes requires a meaningful and long-term commitment in order to maximise the impact of the work. A close collaboration with digital office at the SFOE has been established which will help to achieve this goal.

The database requires industrial thermal demands and load curves. These turned out not be available as published results from existing research and will therefore depend on outputs from WP4. Data collection for this has been doing in WP4 and generation of load curves is ongoing. WP4 adopts Process Integration (PI) methodology to characterize process energy demands, aiming at both company and sectorial levels. Task 4.1 of WP4 aims to collect, collate, and evaluate plant data of industrial companies, to understand and obtain the temporal profile of energy demand in terms of both quantity and quality (energy profiles) at the company level. This is achieved through systematic evaluation of the PAs data conducted and collected in Switzerland. HSLU-TEVT is currently populating a database, which will include the energetic and economic parameters of these PA. The parameters of these PA (e.g., energy demand, energy sources, energy supply) will be systematically evaluated, collected and presented in a suitable form. At the same time, the measures developed in the course of the PA are (e.g., energy saving potential, cost reduction, CO2 reduction) are systematically collected, categorized and evaluated according to economic criteria.

The Competence Centre for Thermal Energy Systems and Process Engineering (HSLU-TEVT) of Lucerne University of Applied Sciences and Arts (HSLU) carried out a project to collect and compile all performed pinch analyses (PAs) in the Swiss industry from the year 2007 to 2019. A PA provides important insights into the absolute energy saving potential of an overall system and with which measures this can be correctly exploited, e.g., heat recovery, optimization of the energy supply, use of energy conversion systems, energy storage.

[1] Chambers, Jonathan, Mercedes Rittman-Frank, and Martin Patel. 2021. "Presentation of New Geospatial Datasets for Renewable Thermal Energy Systems Modelling in Switzerland." Journal of Physics: Conference Series 2042 (1): 012003. https://doi.org/10.1088/1742-6596/2042/1/012003.

Nr. of datasets	Sector
4	other
5	textiles
4	pulp and paper
24	food and beverage
3	minerals
13	metals
1	electronics
9	chemicals and pharmaceuticals

Table 1 Number of available data sets from pinch evaluation with respect to industry sector.

The work to convert the studies into representative sector load curves is ongoing and will be conducted within Task 4.3. Using statistical analysis on the collected data, construction of exemplary energy profiles (GCCs) that represent the energetic demands and excess heat at company level for various production classes in Switzerland will be completed. For the sectorial GCCs, aggregating individual company profiles into sectorial GCCs aids understanding the energetic demands of the various industry sectors. These profiles are envisaged to be completed by the end of 2022 for the dairy sector.

Task 1.2: Thermal energy system model

Initial work was conducted on thermal energy system modelling using a simplified electrification model and cost optimisation method. The aim of this model was to study the shares of technologies for providing clean heat service in a decarbonised heat scenario, considering building energy retrofit, decentralised heat pumps, and high and low temperature thermal networks with centralised heat pumps. Global sensitivity analysis (GSA) was conducted on this model. Results were published in Applied Energy journal[2].

A methodological innovation of this work was the development of high performance algorithms that allowed modelling of different technologies (notably district heating) at high spatial resolution and with sufficient speed to make techniques like GSA feasible at such resolutions (which imply very large numbers of model evaluations).

The principle finding of this work was to highlight that using cost optimisation as the core modelling method is unlikely to provide robust results, because costs of different low carbon heat options are within relatively small margins of uncertainty of each other.

This finding has significant implications for energy system modelling and future projections. System cost, calculated as the levelized cost of heat service equivalent, is not likely to be the primary decision-making factor in choosing the future energy system, since there is not much to distinguish between different options in terms of levelized costs.

For future research, this implies a need for a richer decision-making model when creating system models intended to provide scenarios and pathways for the energy transition in the thermal sector. Assuming that the least cost path will be chosen on the basis of assumptions of a fully efficient free market economy will not produce robust results. Instead, more dimensions of the decision process need to be taken into

[2] Chambers, Jonathan, M. J.S. Zuberi, K. N. Streicher, and Martin K. Patel. 2021. “Geospatial Global Sensitivity Analysis of a Heat Energy Service Decarbonisation Model of the Building Stock.” Applied Energy 302: 117592. https://doi.org/10.1016/j.apenergy.2021.117592.

account, such as what are the different possible strategic driving forces from the policy side, for example if there is a nation-level drive towards more or less energy independence.

Implications for implementation of district heating in particular need to be further studied, as the development of district heating implicates different stakeholders with different interests and cost/benefit assumptions (e.g. governments, system vendors/operators, citizens/customers). The socio-technical complexity highlights the limits of purely cost-optimisation modelling approaches for predicting or evaluating future scenarios and transition pathways. In this context, enhanced collaboration with WP2: business dynamics is being sought in order to ensure that an understanding of the evolution of decision making processes are taking into account at the early stage of the development of the whole system model. This is being worked on in synergy with the Innosuisse GENEAP[3] project at UNIGE which is developing the TESSA energy system planning tool.

For policy, we recommend acknowledgment of the limitations of least-cost approaches to heating decarbonisation, with the understanding that there are a large range of whole-system configurations that fall within a relatively small range.

Another important finding of this work was there high spatial variation of the levelized costs, the sensitivity of the levelized costs, and the variance of the fraction of heat service provided by the different technologies (see Figure 1). The spatial variation is strongly correlated to building density. In dense urban areas there is a large variability in the possible technology mix, since the high densities mean that small changes in model parameters (mainly technology costs and efficiencies) result in large changes in the apparent potential for that technology. However, it is important to bear in mind that this is a result of using cost optimisation as the technology selection method, rather than this necessarily reflecting the reality of technology adoption.

Costs also show a large spatial variability. In dense urban zones, costs per unit energy tend to be lower because of the high energy densities. This has implications for policy, raising questions of social equitability and the fair distribution of costs taking into account the different opportunities and incomes (e.g. costs for single family homes tend to be higher, but incomes of occupants of these homes are likely to be higher also). Further work is needed to address this topic.

Task 1.3: Scenario analysis and transition pathway

To be started later in 2022.

Task 1.4: Link to full energy system model

To be started later in 2022.

[3] https://www.aramis.admin.ch/Grunddaten/?ProjectID=48609

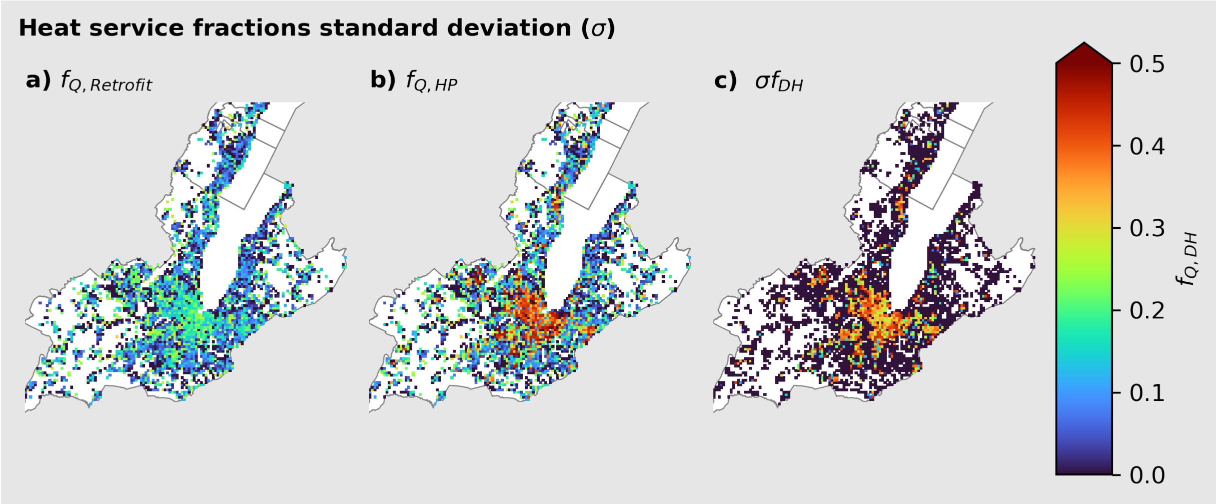


Figure 1: Illustration of model results in the Geneva region, showing the variability (standard deviation) across the sensitivity analysis model runs of the fractions of heat provided by the different technologies.

3.2 WP 2: Understanding legal and socio-economic integration of clean heat and cooling solutions

Title	Understanding legal and socio-economic integration of clean heat and cooling solutions			
Actual start	*04/2021*		**End**	*03/2024*
TRL range	**Starting at**	*N/A*	**Ending at**	*N/A*
WP leader	*Matthias Speich & Silvia Ulli-Beer, ZHAW Institute for Sustainable Development (ZHAW-INE), Matthias.speich@zhaw.ch*			
Members and coop. partners	*Andreas Abegg, ZHAW-ZOW* *Roman Bolliger, INDP* *Jonathan Chambers, UNIGE-EE* *Luca Baldini, ZHAW-ARCH* *Empa, OST-SPF, HSLU-TEVT*			
Objectives				
WP02 focuses on the legal and socio-economic integration. It evaluates ways to reduce legal, social, and economic barriers for the development and implementation of clean heat and cooling solutions. WP02 enhances the understanding of interests and conflicts as well as synergies between various actors. It focuses on promising policy measures, strategies, and legal frame conditions to accelerate the implementation of clean heat and cooling solutions.				

Work performed and results

Task 2.1: Actor Analysis (Lead: Matthias Speich, ZHAW-INE)

The aim of this task is to gain an overview of the actors involved in the heating / cooling sector in Switzerland, focussing on district heating and industrial process heat as the two main topics of DeCarbCH. This provides an empirical and conceptual basis for the elaboration of new business models and policy measures (Tasks 2.2 and 2.3), as scheduled for the next three years. The empirical basis used in the first reporting period consists of the 17 semi-structured interviews with decision-makers in Swiss manufacturing firms (cf. Task 5.3 for more details), stakeholder workshops in the complementary project RENOWAVE[4], interviews and scoping meetings with different actors of the Swiss energy sector (utilities, city administration, planners, energy consultants, technology providers, manufacturing companies, entrepreneurs), as well as secondary data such as open datasets, policy documents and company documentation. Besides conceptual advances (see below), these activities and materials allowed us to identify some practically relevant focus areas for subsequent research in DeCarbCH and new complementary projects. In particular, we identified the following topics of interest: tariff models for district heating networks, digital tools as intermediary resources supporting the transition process, and options to valorize energy efficiency or emissions reductions in multi-actor settings (e.g. external use of industrial waste heat).

To elaborate adequate business models and policy measures, it is essential to define a conceptual framework to handle the dynamic complexity of socio-technical systems such as the Swiss district heating and process heat markets. According to the state of the art in international research, business models and business model innovation can play a powerful role in enabling socio-technical transitions. However, how new business models in the energy sector interact with policy frameworks and

[4] https://www.innosuisse.ch/inno/de/home/forderung-fur-schweizer-projekte/flagship-initiative/15-flagships.html

infrastructure development is an under-explored area of research. There is therefore a research gap when it comes to providing guidance for the design of new business models and policy measures to support the integration of renewable energy sources for heating and cooling. We therefore chose to adopt a business ecosystem perspective as a conceptual framework. The business ecosystem concept describes the interactions between multiple interdependent organizations involved in providing a systemic output, and with their broader environment. While this concept has provided useful practical insights in the private sector, it has rarely been applied to low-carbon energy transitions. We therefore related business ecosystem theory to the specific challenges of energy transitions, such as ensuring the match between customer value (e.g. affordable and reliable energy supply), business value (e.g. profitable operation of district heating grids) and public value (e.g. reaching emission reduction goals in time). This conceptual work is described in a manuscript submitted to the Journal of Cleaner Production (Speich & Ulli-Beer, forthcoming), including an illustrative case study on the district heating ecosystem in the Biel agglomeration. This work provides the conceptual basis for further work in DeCarbCH, as it enables us to define 1) the variables to be collected during interviews and workshops, and 2) a conceptual model of the relevant dynamics, to be refined through empirical research. Together with the manuscript on industrial process heat decarbonization (Hafner et al, forthcoming; cf. Task 5.3), this work forms Deliverable D2.1.1.

<u>Task 2.2: Identification and assessment of variants of socio-technical innovations (Lead: Matthias Speich, ZHAW-INE)</u>

In the first reporting period, work on this task has focused on policy solutions. Concretely, a concept was developed for investigating the effects of the new energy law in the canton of Zürich. On 28 November 2021, the population of the canton of Zürich voted on and accepted a new energy law which foresees that a switch to renewable energies is in principle mandatory when a heating system is replaced. Based on this background, a concept for research activities was developed with a view to investigate:

- what impact the new law has on the market of heating systems, which actors are most important, and which motivations they have,
- which technological solutions are applied and to what extent which exception clause to the new cantonal energy law is applied,
- how easily the law can be implemented or which challenges occur in practice,
- to identify a potential need for adapting the law to improve achievement of the law's targets and to accelerate the decarbonisation of the heating sector in the canton of Zürich.

A related concept note was discussed with the canton of Zürich in March 2022. It was recognized that the canton of Zürich cannot provide additional funding for investigating these research questions, however, the research team was encouraged to interact with individual communes in the canton of Zürich, which are responsible for implementing the law, with a view to investigate at least some of the research questions.

Further interaction took place with the canton of Glarus, where a similar new energy law had been accepted by the Landsgemeinde on 5 September 2021. The new law also foresees an obligation to switch to a renewable energy based heating system when a heating system is replaced. Potential research questions for investigating an appropriate design of the implementation of the law and for investigating its effect were discussed with the canton of Glarus.

Through these activities, the foundations could be led for advancing the investigation of related research questions further in the project, ideally with additional co-funding from communes, cantons or the association of communes or the association of cities, and to facilitate exchange on related topics among policy actors concerned.

Another activity related to this task was the successful acquisition of the SFOE-funded project TCology[5] (Lead: ZHAW-ARCH), with participation of ZHAW-INE. This project examines potential applications for sorption-based thermochemical networks. This project, as well as a potential follow-up, will contribute to D2.2.2 by proposing measures to support the diffusion of an emerging technology.

Task 2.3: Socio-economic dynamics of the implementation of pathways to a net-zero heating and cooling

To be started early 2023.

Tasks 2.4 & 2.5: Legal frameworks (Lead: Andreas Abegg, ZHAW-ZOW)

This work focused on two different areas.

District heating:

- Work performed: Research on legal questions concerning the planning, construction and operation of district heating systems. These issues were addressed through doctrinal legal analyses. A journal article was published in 2022 (Abegg/Musliu, sui generis, pp. 43 ff.)
- Results, findings and experiences: The research shows that the main competences lie with the Cantons, while the federal level merely sets general standards concerning the efficient energy consumption. Absent legal provisions to the contrary, energy provision is not a state responsibility but left to the private market actors. District heating systems may figure in public plans; their construction requires a permission. Additional permits are required for district heating systems built on public ground. Further, special procedures must be followed if monopolies are established or if the provision with energy is a state responsibility that shall be mandated to a private operator. Finally, the law may make it mandatory to connect buildings to a district heating system. As the flipside to this, issues of discrimination must be avoided which would arise if only some but not other building owners in similar circumstances could connect their buildings to the district heating system.
- This research contributes to clarifying the legal barriers to green cooling and heating solutions: It clarifies the law that governs district heating systems.
- This research contributes to deliverables 2.4.1: It analyses the legal requirements in the planning process, the permits and the operation and use of district heating systems.
- This research contributes to deliverable 2.5.1: It gives an overview of the current state of the legal rules governing district heating systems.

Biomass Plants:

- Work performed: Research on legal framework in relation to Biomass Plants: The relevant legal provisions and case law in relation to biomass power plants were critically analyzed according to the usual methods used in jurisprudence. The research was carried out in 2021 and the results

[5] https://www.aramis.admin.ch/Grunddaten/?ProjectID=50073

were published in 2022 (publication: Beatrix Schibli, Biomasseanlagen in der Landwirtschaft, in: Schriften zum Energierecht, Zürich 2022).

- Results, findings and experiences: Biomass plants are conform to zone requirements in agricultural zones under restrictive conditions. Besides, legal provisions of the Federal Ordinance on Spatial Planning turn out to be more restrictive than the Federal Act on Spatial Planning. Recommendations were made how to revise the legal provisions of the Federal Act on Spatial Planning.
- The results contribute to achieving the objectives of the WP 2: Biomass plants contribute to green heating.
- This research contributes to deliverables 2.4.1, 2.4.2, 2.5.1: It analyses the legal requirements in the planning process, the permits and the operation and use of district heating systems.
- Significance of the results for implementing Switzerland's Energy Strategy 2050 and achieving the country's climate goals. Highlight:
    - Biomass plants contribute to implementing Switzerland's Energy Strategy 2050
    - The work (publication) shows how the legal provisions should be revised in order to increase legal certainty in relation to the construction of biomass plants.

3.3 WP 3: Technologies, design, and operation of thermal grids for future energy planning

Title	Technologies, design, and operation of thermal grids for future energy planning			
Actual start	*03/2021*		**End**	*02/2025*
TRL range	**Starting at**	*3*	**Ending at**	*6*
WP leader	*Willy Villasmil, HSLU-IGE, willy.villasmil@hslu.ch*			
Members and coop. partners	*Luca Baldini, ZHAW-INE* *Maurizio Barbato, SUPSI* *Marco Belliardi, SUPSI* *Andrew Bollinger, Empa* *Vinicio Curti, SUPSI* *Massimo Fiorentini, Empa* *Binod Koirala, Empa* *Stefan Mennel, HSLU-IGE* *Florian Ruesch, OST-SPF* *Matthias Sulzer, Empa* *Riccardo Toffanin, SUPSI* *Jörg Worlitschek, HSLU-TES*			
Objectives				
Thermal grids allow to distribute renewable energy and to recycle waste heat (e.g., from cooling or industrial processes) for heating applications. WP3 develops technical solutions for future thermal grids and grid-connected applications like thermal storages. It develops a solid understanding of new thermal grid concepts and its underlying control algorithms to form a base for future energy planning.				

Work performed and results

Task 3.1: Representative cases for renewables and storages in thermal grids

An extensive literature review has been performed to determine common characteristics of thermal networks that allow the definition of representative network archetypes. These archetypes will allow establishing a standardized framework to analyse current and future networks. Potential stakeholders benefiting from this description have been identified and relevant descriptive parameters has been found using the underlying data of the **SFOE database on thermal grids** (opendata.swiss). This work contributes to the deliverable D3.1.1.

The archetypes approach will provide a solid understanding of thermal grids on an overall system level and aim at reducing technical complexity toward an accelerated implementation based on local techno-economic and legal boundary conditions. Representative cases will be generated based the underlying network archetypes. Therefore, the definition of representative districts has been purposefully shifted to a later stage of the project.

The process of defining the archetypes is ongoing. The **main data source** (opendata.swiss, virtually the only database that systematically collects Swiss data on thermal networks) virtually lacks very relevant parameters (such as network temperature and primary energy sources breakdown) so a process to efficiently collect relevant missing data has been initiated with Swiss District Heating Association and other experts in the field.

Task 3.2: Technology options for the integration of renewables in thermal grids

Two complementary SFOE Projects (BigStoreDH[6] and IceGrid[7]) were acquired and started during this reporting period. In both projects, the integration of storage and renewables in thermal grids are analysed based on real-world use cases and generic, typical networks. These use cases include sewage-based low temperature grids, standard high-temperature grids connected to lake water heat pumps as well as grids connected to biomass or fossil CHP plants.

The possibilities of using TRNSYS for the simulation of thermal grids was facilitated by providing a Graphical User Interface (GUI) that generates simulation decks for thermal grids. This GUI is tested and debugged at OST-SPF and will be provided to interested DeCarbCH members.

These use cases and simulations tools are being used to investigate the integration of different renewable energy sources and their combination with solar energy. Results will be condensed in guidelines for the integration of solar energy to thermal grids and the combination with other renewables (D3.2.1).

Task 3.3: Technology options for storages in thermal grids

Two thermal storage concepts are being studied in detail: i) borehole thermal energy storage (BTES) and sorption storages as part of thermochemical networks. Research on thermochemical networks only started recently in the framework of the SFOE project Tcology[8]. High temperature BTES contributes to the challenge of seasonal thermal energy storage which is highly impacting the exploitation of renewable heat, seasonal load shifting and CO_2 emission reduction. It thus directly contributes to the Swiss energy transition. The work performed contributes to D3.3.1.

Within this monitoring period, research has focused on high-temperature BTES as an integral part of a district energy system. The objective is to study the impact of increased storage temperature on the seasonal load shift and the operative CO_2 emissions. In a first simulation study, a simplified dynamic BTES model was developed and used for operational optimization. Different operation modes and temperature/flow rate set-points were assessed. In a second study, the simulation framework was extended to allow for design optimization and identification of optimal system components size. Solar collectors have been integrated to enable charging of the BTES during summer, allowing for better winter performance. The system design optimization was conducted considering different district heating and cooling network supply temperature as a boundary condition, and the impact on the system configuration was analysed.

The developed model can accurately predict the temperature behaviour of the BTES and its charging/discharging capacity while allowing the numerical optimization of the system with high computational efficiency. CO_2 emission reductions of up to 20% with reference to an air-source heat pump/chiller system without BTES were recorded using a high-temperature BTES concept using only waste heat from cooling operations. Enabling at a design stage to change the size of the storage and integrate solar thermal collectors, led to a reduction in CO_2 emission of 40%.

[6] https://www.aramis.admin.ch/Grunddaten/?ProjectID=49260

[7] https://www.aramis.admin.ch/Grunddaten/?ProjectID=49264

[8] https://www.aramis.admin.ch/Grunddaten/?ProjectID=50073

Task 3.4: Design and control of future thermal grids for heating and cooling

The first systematization of the actions that help lowering the grid temperatures, both in new and existing grids as well as in extension of grids, is in advanced status. Supported by thermo-economical modelling, the systematic approach will allow to quantitively classify the actions aiming at reducing the grid temperatures.

These activities contribute to D3.4.1 and is in line with the overarching strategy of increasing the penetration of low-grade renewable heat (e.g., industrial waste heat) into existing high-temperature networks.

Task 3.5: Local Energy planning for future thermal grids

Suitable 'anergy networks' have been identified in Chur as part of a case study foreseen to perform further analysis. One of the objectives is to provide real data that allows improving and adapting the Ehub tool so that temperature dynamics and their impact on system performance can be captured while performing local energy planning for future thermal grids.

Techno-economic and emission data of available energy resources, conversion/storage technologies and energy networks have been gathered. Current and future thermal demand is estimated. These input data are now processed in the Ehub tool and are being further analysed. An alignment with T3.4 and WP6 Case study Zürich has been initiated. A semester project on Anergy Networks for Achieving Net-Zero CO2 in the city of Chur has been performed.

The activities conducted so far in this task contribute to the deliverable D3.5.1. These results will be compared with the results of detailed modelling including temperature dynamics in T3.4 to evaluate the wide range of energy supply – district heating/cooling options.

3.4 WP 4: Energy demand profiles of industry and the potential for renewables integration and negative emissions

Title	Energy demand profiles of industry and the potential for renewables integration and negative emissions			
Actual start	*04/2021*		**End**	*03/2025*
TRL range	**Starting at**	*3*	**Ending at**	*4*
WP leader	*Beat, Wellig, HSLU-TEVT,* beat.wellig@hslu.ch			
Members and coop. partners	*Benjamin H Y, Ong, HSLU-TEVT* *Gianfranco Guidati, ETHZ* *Martin Patel & Navdeep Bhadbhade, UNIGE-EE* *Pierre Krummenacher, HEIG-VD-IGT* *Cordin Arpagaus & Frédéric Bless, OST-IES* *OST-SPF* *ZHAW-INE*			
Objectives				
i) Collect, collate, and evaluate process data of industrial companies, to understand and obtain the temporal profile of energy demand in terms of both quantity and quality (energy profiles) at the company level; *ii) Develop tools and methods to guide users in industry in obtaining their own energy profiles;* *iii) Produce exemplary profiles for various production classes, and aggregated profiles for industrial (sub-)sectors;* *iv) Gain a solid understanding of exploiting negative CO2 emission technology (NET) energy efficiency potential in industry;* *v) Systematically compare profiles with the heating and cooling capabilities of available and emerging renewable solutions to estimate the opportunities for renewable integration, fuel substitutions, and to identify the potential for NET use and the utilization of excess heat.*				

<u>Work performed and results</u>

The aim of Work Package (WP) 4 is to enhance the understanding of the energy demands from industry to facilitate successful integration of energy efficiency measures, and renewables within the process energy supply. The WP adopts Process Integration (PI) methodology to characterize process energy demands, aiming at both company and sectorial levels. Determining industrial energy demand profiles (quantity, quality, temporal), based on real data analysed using state-of-the-art PI techniques, is a crucial precursor to supporting integration of renewable heating and cooling (henceforth termed “renewables integration”), and excess heat use (e.g. in thermal grids), as they form the basis for accurate characterization and eventual matching of demands with suitable renewables technologies emerging and currently on the market.

<u>Task 4.1: Data extraction, collation, and evaluation (lead HSLU-TEVT)</u>

The Swiss Federal of Energy (SFOE) has been promoting the performance of pinch analyses in Swiss industry for years. To date, more than 150 pinch analyses supported by the SFOE have been carried out. A Pinch Analysis (PA) provides important insights into the absolute energy saving potential of an overall system and with which measures this can be correctly exploited, e.g. heat recovery, optimization of the energy supply, use of energy conversion systems (e.g. heat pumps), and thermal energy storage.

The purpose of Task 4.1 is to collect, collate, and evaluate plant data of industrial companies, to understand and obtain the temporal profile of energy demand in terms of both quantity and quality (energy profiles) at the company level. Task 4.1 builds upon the solid body of existing knowledge; industrial energy usage data collected during previous Swiss energy research activities (especially those of the SCCER EIP); through systematic evaluation of selected data from PAs conducted in Switzerland. Thereby, real plant data exclusively from Swiss industry is used to form the energy profiles, taking note of the scale of production, and handled according to the data management plan. Where real data cannot be sourced, previous SCCER EIP studies and literature, as well as data from well-known processes, best available techniques, and statistical data will be used to complete the energy profiles. Task 4.1 formed a core group for temperature levels. The members of the group are HSLU-TEVT, UNIGE-EE, OST-IES, OST-VD, and HEIG-VD-IGT. In this core group, members exchange available information, e.g. industrial process stream data, best available techniques, literature references, etc.. The database for the Pinch study available is growing as more projects and data are being exchanged.

Until now, there has only been a holistic compilation of overview of the PA projects that have been carried out from 2007 to 2019. There is, however, no database that provides all the data that is needed for the PA. In order to cover this gap, a database is created during this reporting period, which includes the energetic and economic parameters of these PAs. The database is built using Microsoft Access. Microsoft Access is an information management tool, or relational database, that helps store information for reference, reporting and analysis. Access can also overcome the limitations found when trying to manage large amounts of information in Excel or other spreadsheet applications. The value it can provide is to store related information in one place, and then let you connect various parameters together. With Access tables, fields, and relationships set up, data entry forms that use those tables to store the information can be created and later create reports (queries) with the data. Currently the database is being populated with the collected PAs through previous projects and through the core group. The parameters of these PAs (e.g. energy demand, energy sources, energy supply) are systematically evaluated, collected and presented in a suitable form. At the same time, the measures proposed in the course of a PA are (e.g. energy saving, investment cost, operating cost reduction, CO_2 reduction) collected, categorized and evaluated. More information can be found in Deliverable Report D4.1.1.

An additional focus will be the development of a systematic evaluation framework based on a top-down/bottom-up approach and covers the important point of data extraction. Generally, in PA, there are three models/depth of modelling, “black box”, “grey box”, and “white box” are used to represent the broad categories of detail level that may be applied to a process. In the PA projects that have been carried out, the baseline of modelling differs. Based on these different types of modelling, how do we get to/as close to the process requirements (white-box) with the grey-box and black-box modelling? The other question is how do we get the scheduling information of the process if the time modelling is aggregated to a total net operating hours?

Two approaches are commonly used to reconcile data in PA, which are used in this work, top-down and bottom-up approaches, or the combination of two. The choice between the two approaches depends on data access, where a bottom-up approach is preferred when detailed process data are available, and the top-down approach can be used in their absence.

Bottom-up approaches rely on gathering primary data from functioning plants in the pertinent industrial sector. In the case of this work, bottom-up approach is used when white-box modelling is used in the PA. However, if a basic mass balance and temperature of streams are given, bottom-up approach can be used to extract industrial data by building thermodynamic models of the different process units. The models help closing the mass and energy balances while ensuring that the system’s thermodynamic constraints, provided that the heat capacity of the streams is known or can be calculated. Top-down approach can be adopted at this stage to validate the data.

Top-down approaches are also valid for reconciliation of data and produce a similar result, though the deep details accessible for plant operators cannot be leveraged. High-level data such as the best available techniques/reference documents serve as a starting point and provide some process details, depending on which process is being assessed. Top-down analyses starts from the company's energy consumption and determining the key processing units for a particular plant. This can be compared with literature data, or other plant data to facilitate a common structure exists between industrial processes in the same subsector. Correlation may be used on the energy consumption with production volumes to analyse the possible process requirements. These methods apply for the scheduling as well.

Task 4.2 Developing practical methods and tools for use in Industry (lead HSLU-TEVT)

It is proposed to start Task 4.2 later and to give priority to Task 4.3.

Task 4.3: Characterization of energy profiles (lead HSLU-TEVT)

With the database from Task 4.1, construction of exemplary energy profiles (Grand Composite Curves, GCCs) and sectorial energy profiles is carried out for Task 4.3. This is work in progress, where statistical analysis on the collected data is conducted, and construction of exemplary energy profiles that represent the energetic demands and excess heat at company level for various production classes in Switzerland will be completed. This is important for scoping studies to encourage industrial companies to transition toward renewables. It will allow practitioners to scale the exemplar energy profile according to their production size to explore their potential renewables integration opportunities.

For the sectorial GCCs or Source Sink Profiles (SSPs), aggregating individual company profiles into sectorial profiles aids the understanding of the energetic demands from the various industry sectors or sub-sectors. Figure 2 shows an example of a sectorial SSP for the sub-sector meat. Using this sector-wide profile, the residual energy demands of the sub-sector (assuming all internal heat recovery is achieved) can be identified, along with the potentials for energy efficiency measures (e.g. heat pumps), integration of renewables for heating and cooling, and for excess heat use. The work on these profiles in Task 4.3 is still in progress.

Task 4.4: Opportunities for negative emission technologies (NETs) (lead ETHZ)

In some industrial companies in Switzerland, the required process heat is at temperature levels unreachable by solar, geothermal sources, or heat pumps. Such processes require fuel combustion, although fossil fuels will likely be untenable in a net-zero scenario unless the resulting CO_2 is captured and stored. However, if fuels are biogenic in origin, capturing and storing CO_2 can generate negative emissions, i.e. net removal of CO_2 from the atmosphere. These are also needed to compensate for emissions from outside the energy sector. Two routes exist:

1. Post-combustion capture: requires CO_2 separation from flue gas of combustion systems that deliver high-temperature process heat.
2. Pre-combustion capture means that biogenic fuel, e.g. biomass or biogas, undergoes a transformation into hydrogen (or hydrogen-rich fuel such as synthetic natural gas) and storable CO_2.

In the latter, hydrogen can be burned to generate process heat without the need for CO_2 capture. Both routes have their inherent challenges: the post-combustion approach requires distributed, small-scale CO_2 separation facilities and CO_2 collection from various sources. The precombustion approach requires biomass or waste conversion in centralized facilities which simplifies CO2 collection but requires distribution of hydrogen to industrial processes.

Task 4.4 delivers opportunities and characteristics of NETs (esp. energy balances and costs) in the industrial context. We suggest to shift this task by one year.

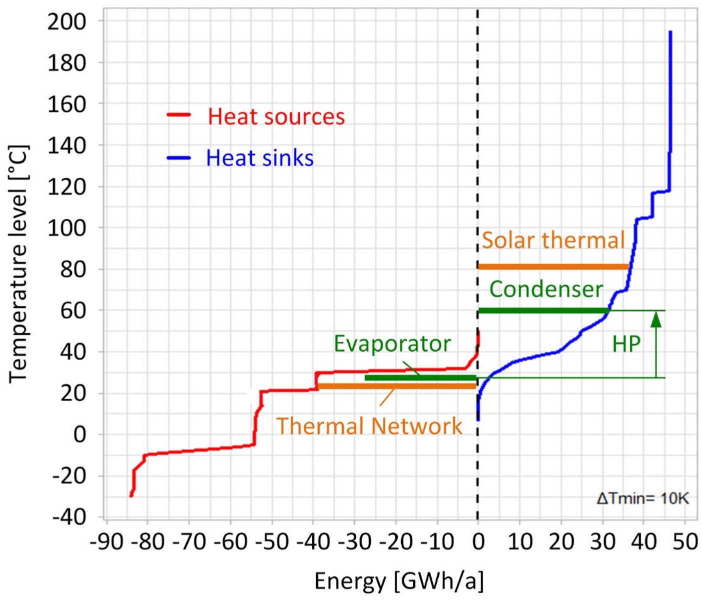


Figure 2: Example of a sectorial Source Sink Profile for the meat industry.

<u>Task 4.5 Quantification of opportunities (lead: HSLU-TEVT)</u>

This task will start in 2023.

<u>Significance of conducted work:</u>

Predicting the impact of new technologies and process improvements toward the goals of ES2050 climate strategy of the federal government must be based on realistic representations of the industrial processes in Switzerland. Major sectors in Switzerland, defined by their energy use, have typical energy demand profiles. In T4.3, the construction of sector-wide profiles provides a vehicle for extrapolating the impact of new technologies, process improvements, and more importantly the integration of renewable for heating and cooling in the major Swiss industries, which provides a window into the opportunities available within these major processes for process integration and application of new technologies. Predictions for the resulting scenarios and the national impact of measures to improve energy efficiency in industry can be made. These extrapolated results can also help identify the type of renewable that would be suitable to be integrated for the heating and cooling of the industrial sector.

The direction of the exemplar profiles leads to high implementation potential, based primarily on their relevancy for SMEs, which are a large portion of industrial energy demand and greenhouse gas emitters. It will provide a quick "energetic fingerprint" of an industrial company. This is important for scoping studies to encourage industrial companies to transition toward renewables. It will allow practitioners to scale the exemplar energy profile according to their production size to explore the economical energy efficiency measures and their potential renewables integration opportunities.

3.5 WP 5: Combination of renewables, heat transformation and storage for medium and high temperature heating as well as cooling

Title	*Combination of renewables, heat transformation and storage for medium and high temperature heating as well as cooling*			
Actual start	*04/2021*		**End**	*03/2024*
TRL range	**Starting at**	*6*	**Ending at**	*8*
WP leader	*Stefan Bertsch, OST-IES*			
Members and coop. partners	*OST-SPF* *HSLU-TES* *ZAHW-INE* *ZHAW-ZOW* *EMPA* *HSLU-TEVT*			
Objectives				
This work package will focus on the optimum combination of existing and forthcoming technologies to reach medium and high-temperature heat as well as cooling at different power levels. These solutions for carbon free heating and cooling will consider the possible temporal (storage) and spatial (transport) mismatch between supply and demand of real-world situations. The outcome will be technical solutions for a high level of renewable energy and efficiency measures with suggestions for an accelerated market introduction.				

Work performed and results

Task 5.1: System solutions for the integration of renewables to deliver medium and high temperature heat (lead: OST-IES)

One major activity in the first year was to interface with the other WPs, to understand what information is needed – especially on heating devices – and how this information may be stored and accessed (see WP1). Especially the input of WP4 is important because it informs task T5.1 on the typical temperatures and powers needed in the Swiss industry which helps focusing on the most relevant solutions for Swiss industries. Data collection on various heating devices relying on renewable resources for the database has started.

The list of the solutions for the integration of renewables to deliver medium and high temperature heat is currently being made, therefore, there is no complete result yet. Data collection has started.

The results of Task 5.1 is crucial for the achievement of WP5 as it will list the current technologies for heating and cooling using renewables. Knowing the technology very precisely is crucial for the SWEET DeCarbCH objectives as it can be used in all other WPs (from the use in complex simulations, up to studying their acceptance).

This task will contribute to achieve deliverable D5.1.1 (simulation model of several energy concepts for typical industrial profiles set up and database of solutions) which will use the result of T5.1 and industrial profiles from WP4. Deliverables from another WP such as D3.1.2 (Techno-socio-economic assessment of storages and renewables in grids), D2.2.1 (Workshop minutes for elaboration of socio-technical variants), D2.4.2 (Proposals on more efficient procedures and on how acceptance is to be increased when building thermal and cooling infrastructure) will also use some of the results of Task 5.1. Finally, the WP5 deliverables D5.1.2 (Catalogue of optimal system solutions based on power, storage and temperature requirements and available resources) and D5.2.1 (Case study on impact (ecological, economic, risk) and optimum level of renewable energy integration supported by power/consumption time series analysis) will be using the results of Task 5.1. From a current perspective, all milestones and deliverables can be fulfilled within Task 5.1

This task will indirectly help with the Switzerland's Energy Strategy 2050 to achieve the country's climate goals by providing an up-to-date and searchable list of renewable technologies and combination thereof to create heat at medium and high temperature levels. Therefore, this tasks results will be used as a tool in many tasks of DeCarbCH and will be available to other SWEET consortia via the CROSS platform. Task 5.1. will not directly influence policies. This task is innovative in the combination of the technologies specially regarding thermal storages.

Two related projects have started with the SFOE on the integration of high temperature heat pumps in industrial settings. Their results will be included in the outcomes of Task 5.1 and might lead to a P+D project.

Task 5.2: Increasing the share of renewables in existing solutions with digitalisation approaches and determination of optimal integration level for renewables (lead: HSLU-TES)

The first step during this reporting period for Task 5.2 was to provide an overview of suitable digitisation methods and to demonstrate methods with which decarbonisation with digitalisation methods can be achieved. In two related projects, two case studies where anomaly detection of energy consumption and process optimisation were performed to identify non-efficient processes and sites. The other focus during this reporting period was laid on finding the industrial sector which provides the maximum lever arm for decarbonisation of the industry. For this, also input from WP4 was taken into account.

Various methods to perform anomaly detection and process optimisation were developed and tested. Analysing the CO2 emission aggregated on the NOGA levels, five industries with the most promising lever arm for decarbonisation were identified (chemical and pharmaceutical products fabrication, production of paper, food, glass and ceramics). Contact with representatives of each of these industries is now established and interviews were or will soon be performed. An overview over digitisation solutions from the literature is under way.

The global objective of decarbonisation of the thermal energy needs in Switzerland is focused in this work package on the industrial demand of thermal energy. The results of T5.2 enable the identification of suitable industrial sites and branches that may profit from the solutions developed in WP5.The support by the energy data analytics will help to identify where the deviations of the considered site from the expected theoretical consumption behaviours as described in WP4 arises. Eventually, the results will help to identify the bottleneck and support their resolution. These results will increase the impact for the use cases in T5.2 as well as the efficiency optimisation in the P&D work package WPPD3.

The case study on the impact and optimum level of renewable energy integration and the anomaly detection methods help to identify suitable candidate industrial partner and to identify challenges in the considered site. These results help to provide the use cases supported by a time series analyses (D5.2.1) as well as the online database of use cases (D5.2.2). The successful completion depends on collaboration with an industrial site on demonstrating methods of digitalisation to decarbonise the site. First interviews with representatives of industrial sites have taken place, as mentioned above.

This task will help pushing the implementation of the Energy Strategy 2050 as it will provide showcases of decarbonisation of industries which will deploy baseline examples for further decarbonisation projects. Furthermore, the study on the broader applicability of the results will help to generate a map of the potential for the replicability of the developed methodology. Thereby, it will pave the road to new policies based on the implementation benefit and potential maps. Also, it will show innovative measures for specific sites on how they concretely could lower their CO2 emission. The results will be complementary to the other SWEET projects as they could showcase ways of decentralized energy production (for **SWEET EDGE**) or sector coupling (for **SWEET PATHFNDR**).

Task 5.3: Accelerating integration and industrial market penetration (lead: ZHAW-INE)

For this task, in a first step, the drivers and barriers of decarbonization measures for process heat were investigated in the specific context of the Swiss manufacturing sector. In collaboration with the related project SERENDIP[9], 17 semi-structured interviews were performed with decision-makers (CEOs, board members, energy managers) in the food and beverages, chemical and pharmaceutical, equipment and non-metallic minerals sectors. The aim was to identify the main factors influencing decisions to invest in decarbonization measures. The definition used for “decarbonization measures” includes the whole range of options available to reduce GHG emissions from process heat, i.e. energy efficiency measures, fuel switching, electrification and product modifications.

We followed a theoretical sampling approach, in which data collection and analysis were done iteratively, and new interviewees were selected based on the potential to obtain new information or fill information gaps in the existing data. The interview questionnaire, as well as the data analysis, were structured according to a well-known management framework, the St. Gallen Management Model. This allowed us to assign barriers and drivers to distinct firm-internal categories, as well as external stakeholder categories and broader environmental spheres. Results showed that many important barriers are due to the interaction of internal and external factors. For example, internal financing is an often-cited barrier for investment. This barrier can be acted upon in different ways, e.g. by seeing decarbonization as a competitive advantage (firm-internal factor), seeking and taking advantage of solutions to valorize energy efficiency or emission reduction (together with external stakeholders), or through supportive policy frameworks (broader environmental spheres).

In international policy research on industrial decarbonization, there is an ongoing debate: on one hand, some researchers argue that carbon pricing and R&D support are the first-best solutions to drive private investment into decarbonization measures. Others argue that this combination is not enough to drive systemic rather than incremental change, and that other, complementary policy tools are necessary to reach net-zero emissions. These options include new partnerships between private and state actors, the (re)designing of markets or the active management of phase-outs. Our results support the latter side of this debate: while the role of carbon pricing is crucial, our findings also highlight the relevance of other measures (e.g. increase of information, incentives for the development of, and the demand for, new technologies) introduced both by the government as well as by other stakeholders.

Our findings give evidence that the actions of customers, competitors (decarbonisation becomes a competitive advantage), consultants and the state & policymakers have been relevant to steering the low-carbon industry transition so far. Given the interrelated nature of investment barriers and drivers, we suggest that future policy options focus on coordinating the interaction between different stakeholders and incentivising the alignment of different stakeholders’ actions. The elaboration and assessment of concrete solutions to accelerate the integration of low-carbon technologies is foreseen in Task 2.2. This will form the basis for Deliverable D5.3.2.

[9] https://www.zhaw.ch/en/research/research-database/project-detailview/projektid/4224/

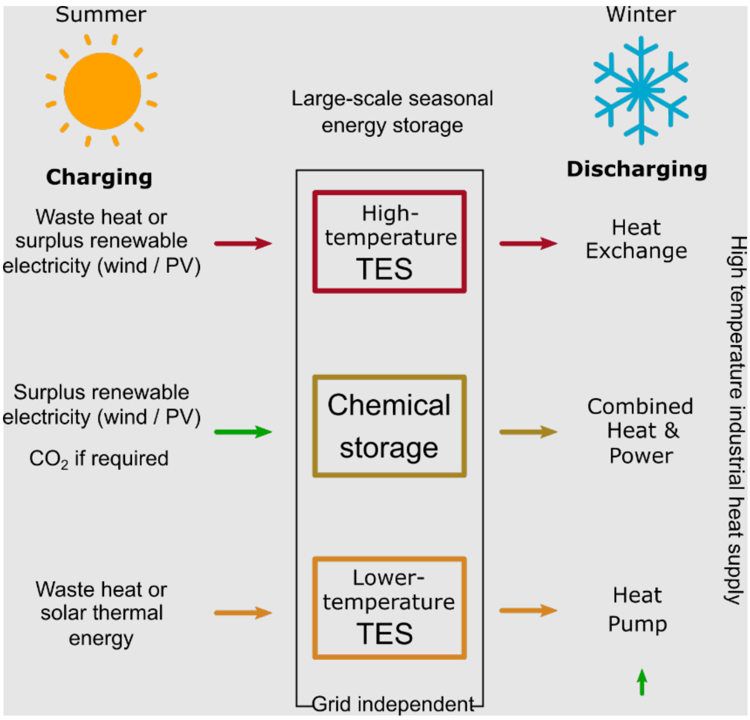
Industrial decarbonization is a highly complex task involving multiple actors, multiple levels of decision-making, as well as shifting technological, economic, regulatory and cultural boundary conditions. To monitor the progress and identify new challenges as well as possible solutions, a regular survey is foreseen. The qualitative study performed here provides the empirical basis for a periodical representative, quantitative survey. Furthermore, this work allowed us to characterize the business ecosystem around industrial decarbonization, thus contributing in the short term to Deliverable D2.1.1.

Task 5.4: Medium and high temperature renewable heat in peak season (lead: OST-SPF)

The outcome of Task 5.4 within the reporting period is a techno-economic report on longer term storage solutions with the focus on grid independent options that are able to supply process heat at temperatures between 80 and 150 °C in winter. At first, literature research on storage solutions was performed and the main criteria as well as potential storage options were identified. Additionally, a cost assessment was performed comparing various technologies.

Low capital cost and high energy storage density are of particular importance for longer term energy storage solutions. Therefore, the options were narrowed down to two categories that seem to be the most promising in terms of economic viability for seasonal energy storage:

- Thermal Energy Storage (TES)
- Power-to-X-Heat using “renewable fuels” (sector coupling)



Long term TES at the target temperature levels of 80 – 150 °C can only be operated with acceptable losses and cost if the surface to volume ratio is very low, or if the ambient that surrounds the TES is at a similar temperature. The latter may be the case for aquifer storage (ATES) at a corresponding depth. In Switzerland, temperatures of more than 100 °C are typically found underground at a depth of a few thousand meters. Besides such deep ATES, also shallow ATES, boreholes (BTES) or pit storages

(PTES) may be realized in the ground. For PTES, the temperature limit is below 100 °C and therefore cannot serve the same temperature levels as ATES or, possibly, also BTES. For on-ground installations, tank configurations (TTES) are the state of the art, but water tanks need to be constructed for higher pressures when operated above 130 °C, which increases cost and makes this solution less attractive for long term storages. In addition, low temperature storage of any type may serve for increasing the source temperatures for heat pumps and therefore increase efficiency of heat pumping processes.

Power-to-X achieves much higher (factor 20 – 300) volumetric energy densities than thermal storage and, once energy is converted into the storable form X, losses until use are minor. This makes power-to-X technologies interesting candidates for delivering process heat at 80 – 150 °C in peak seasons, while possibly also delivering electricity at the same time. Hydrogen (H2), methane (CH4), methanol (CH3OH) or ammonia (NH3) and metals (Fe, Al) are promising candidates for Power-to-X-to-Heat pathways for storing larger amounts of energy (up to 100 TWh) over long periods. The overall production costs of the alternative fuels, such as ammonia, methane, and methanol are in general more expensive when compared to the production of renewable hydrogen. However, the cost for containments (tanks) of these alternative fuels are in general less expensive when compared to the direct storage of gaseous hydrogen. Using renewable metal fuels, heat and electricity can be cost-effectively supplied anytime, anywhere, and even in small units. Studies at OST-SPF have shown that the production of heat and electricity from aluminium is possible on a laboratory scale and can be realized with a high efficiency of more than 90%. SPF-OST is continuing work on this process within an on-going Innosuisse project and a new Horizon Europe project just starting.

The result of Task 5.4 is fundamental to achieve deliverable D5.4.1 (report on techno-economical optimal solutions for longer term storages). Additionally, the outcome of this task will be used to perform deliverable D5.4.2 (design of at least two longer-term storage solutions to deliver heat above 80°C) which is due in month 48.

Significance for Switzerland's Energy Strategy: Renewable electricity and heat can be produced cheaply today and short-term storage solutions for evening out mismatches between production and demand are available at low cost. The Energy Perspectives 2050+ show that Switzerland is likely to continue importing electricity and heat in winter also in the future. The storage of large quantities of renewable energy over long periods is still an important unsolved issue. In order to decarbonize the heat supply within the industry sector not only in the summer, but also in winter, and to increase the independency of our energy-supply, long-term energy storage options for renewables are needed. The deliverable that is currently worked out gives an overview on the options for providing heat for industrial processes at temperatures between 80 – 150 °C by the use of seasonal storage options, their state of the art and expectations for cost and feasibility.

Related projects of the SWEET consortia are

- Innosuisse project Alu-CHP[10] from OST-SPF that develops a unit which produces hydrogen and heat in winter based on aluminium as renewable energy carrier (2021 – 2023).
- EU Horizon Europe REVEAL[11] on aluminium energy storage cycle (July 2022 to July 2026), with scientific lead at OST-SPF.

[10] https://www.aramis.admin.ch/Grunddaten/?ProjectID=47536

[11] https://www.reveal-storage.eu/

3.6 WP 6: Case study Zurich

Title	Case study Zurich			
Actual start	*06/2021*		**End**	*06/2027*
TRL range	**Starting at**	*3*	**Ending at**	*6*
WP leader	*Armin Eberle, ZHAW-INE, ebea@zhaw.ch*			
Members and coop. partners	*Research Partners* *Silvia Ulli-Beer, ZHAW-INE; Andreas Abegg, ZHAW-ZOW* *Willy Villasmil, HSLU* *Matthias Sulzer, empa* *Cooperation Partners* *Silvia Banfi, Administration of Zurich (Energiebeauftragte, UGZ, ewz, erz)* *Verena Lübken, e360*			
Objectives				
The work package aims to apply, test validate and improve approaches, tools and results developed in other work packages to concrete locations in the city of Zurich. *We will define topics like the speed of transformation, subsidy schemes for the implementation for thermal grids and the role of the industrial/commercial sector. This empirical work will offer insights into the barriers and success factors of strategies to support the transition. It will also allow to understand the opportunities of applying the strategies to other cities. From a methodological point of view, this WP will lead to deeper understanding whether our methods and strategies are sufficient and appropriate, where and how they successfully complement existing approaches and where on the other hand new or other approaches are required.* *Outcomes* • *Definition of topics and of 3 concrete cases* • *Report on framework conditions underlying cases* • *Test Report of Methods* • *Guideline for successful transition* • *Conclusion on optimized future thermal grids in Zurich*				

Work performed and results (max. 2-4 pages)

The population of Zurich (Canton and City) voted in a referendum May 2022 in favour for a Net-Zero carbon goal until 2040 (Internet www.stadt-zuerich.ch: **Ein neues Klimaschutzziel für Zürich - Stadt Zürich).**

Task 6.1: Identification of current challenges and research contributions with respect to the challenges of the city and the planned transformation of a district (Lead: ZHAW-INE)

The work conducted so far includes:

- Literature review on performed studies and data from Zurich.
- Bilateral meetings with representatives of Zurich (e.g. Energiebeauftragte)
- Workshop with relevant topic related staff from the administration and implementation of Zurich and the research-partners from other WP in order to identify common topics.

- Communication and feedbacks from city to researchers in relevant work packages to establish bilateral communication channels as planned with the partners from the City.

This allowed to identify the following topics of mutual interest:

- Modelling demand (by actors, role of industry)
- Diverse energy supply (heating and cooling) (how, where, when (speed); centralised/decentralized; storage, peak load
- Development of district heating networks, dismantling of gas grids
- Transition (how to get there, legal, social, economic frameworks)

The following fields of high priority were defined:

- Modelling of (local) demand, (city development, efficiency, industry/services, cooling)
- Energy supply: Potential of renewables, dismantling of gas grids
- Development of thermal grids, district heating networks

The following fields of high importance were defined:

- Peak load, energy storage, security of supply
- Pricing, legal framework

Not only the topics have been identified, but also the people to work together in order to find specific locations for implementing cases. Every topic of interest has been assigned at least one contact person from the city administration / utilities and from the DeCarbCH consortium. The ZHAW-INE team is in contact with both sides and acts as a catalyst for the interaction between researchers and implementation partners.

The finding of mutual fields of interest is crucial to identify specific situations to implement scientific findings from the other work-packages. Specifically, of course to achieving the objective of Task 6.1. From discussions with researchers and implementation partners, it became clear that the contributions of researchers should be aligned with the planned activities of the city, whereas at the same time, researchers might be able to suggest new activities or modifications to existing plans. To solve this dilemma, the topic of strategic energy planning was identified as a central issue, where the DeCarbCH consortium can not only make direct contributions, but also help identify contributions in other topics. Unlike most other Swiss municipalities, strategic energy planning in Zurich is revised with a high frequency (every 1-2 years), a policy that offers promising collaboration opportunities. A meeting between implementation partners and researchers involved in the topic of strategic energy planning is planned for Summer 2022.

Task 6.2: Results, learnings for scaling (Lead: ZHAW-INE)

This task will start later 2022

Task 6.3: Thermal grid technologies for the City of Zurich (lead: HSLU-IGE)

This task will start in 2024.

3.7 WP 7: Case studies Romandie: strategies and potentials of temperature reduction on existing district heating networks

Title	Case studies Romandie: strategies and potentials of temperature reduction on existing district heating networks			
Actual start	*8/2021*		**End**	*10/2024*
TRL range	**Starting at**	*6*	**Ending at**	*8*
WP leader	Pierre Hollmuller, UNIGE, pierre.hollmuller@unige.ch			
Members and coop. partners	*Research partners* Alexis Duret, HEIG-VD, alexis.duret@heig-vd.ch Jakob Rager, CREM, **jakob.rager@crem.ch** Matthias Speich, ZHAW, **spei@zhaw.ch** *Cooperation partners* Marcel Ruegg, SIG, **marcel.ruegg@sig-ge.ch** Didier Barth, Coopérative CAD « Le Marais-Rouge », **didier.barth@he-arc.ch**			
Objectives				
Reduction of DH temperature is a priority for integration of renewable heat. It is conditioned by the temperature level of the individual substations, on the secondary side of the heat exchanger (distribution/demand). Latter issue is of particular concern in the case of existing buildings, where distribution temperatures are known to be high, and where corrective actions within inhabited spaces is of particular complexity (in particular for multifamily buildings). Several techniques for temperature reductions at substation level have been proposed or are currently under investigation, but their actual implementation on existing DH substations depends to a large extent on pre-existing conditions. Furthermore, the actual benefit of temperature reduction at the level of the DH network, as well as interaction between temperature reduction strategies and other energy policy measures, need to be analysed on specific case studies. Within this WP, these issues will be tackled by way of case studies on existing DH systems, in urban and rural context.				

<u>Work performed and results</u>

<u>Task 7.1: Temperature reduction in existing District Heating (DH) substations</u>

A literature review was performed on issues related to control and lowering of DH substation (SST) return temperatures (advantages, frequent problems, error detection, optimization methods, alternative architectures).

The two DH case studies were characterised:

- SIG (Genève): Cantonal utility; 220 MW (gas boiler + waste incineration); Urban area, post-war MFB building stock; Mostly standard / pre-existing SST architecture; Forward: 90-110°C / Return: 70-90°C ➔ standard / complex case
- Marais-Rouge (Ponts-de-Martel): Cooperative; 2.25 MW (biomass boiler with condensation); Rural area, 88 old buildings (mainly < 1920); Optimization of secondary side of heat distribution (SST architecture, hydraulic balancing & flowrate regulation); Forward: 70-83°C / Return: 40°C ➔ Exemplary case

Analysis of DH substations (SST):

- Review of pre-existing SST analysis (internal to SIG).

- Collection and pre-analysis of existing monitoring data (2 - 10 years of data, time step 10 minutes + monthly invoices).
- Identification and compilation of meta-data (building address, type of building, rated load of heat exchanger, heated surface, …)
- Ranking of SSTs with the "Heat Customer Analysis" tool by Verenum
- Identification + visit of SSTs to be analysed in priority
- Development of a factsheet template for characterization and pre-analysis of individual SSTs

A technical report concerning the description of case studies and auditing method will be finalized by July 2022 as D7.1.1.

Task 7.2: Impact of different temperature lowering strategies at the level of DH networks

Not yet active (start: April 2023)

Task 7.3: Interaction between temperature reduction strategies and other energy policy measures

Not yet active (start: January 2024)

Task 7.4: Comparison of different measures and governance arrangements for the implementation of temperature reduction strategies

Preparation of semi-structured interviews with the different actors of the district heating ecosystem (Task 2.2), with inclusion of the specific topics covered in this case study (temperature reduction).

3.8 WP 12: Generation of negative CO2 emissions

Title	Generation of negative CO2 emissions			
Actual start	*06/2021*		**End**	*03/2025*
TRL range	**Starting at**	*X*	**Ending at**	*X*
WP leader	*Gianfranco Guidati, ETHZ, gguidati@ethz.ch*			
Members and coop. partners	*Gianfranco Guidati, ETHZ* *Beat Wellig, HSLU-TEVT* *Benjamin Ong, HSLU-TEVT*			

Objectives
The objective of WP12 is to identify negative emission technologies that allow Switzerland to meet its climate goals. This will be done in three steps: (i) the ranking of NETs in the context of the overall energy transition, (ii) detailed design studies on the most important NETs, (iii) definition of a Pilot & Demonstration project for the most promising NET.

<u>Work performed and results</u>

A number of developments took place since the definition of the DeCarbCH project proposal that need to be reflected in the execution of WP12:

- The topic of sustainable aviation fuels has surfaced early 2022 with a series of workshops organized by the BAZL (Bundesamt für Zivilluftfahrt). While the associated emissions were not factored into the latest update of the Energieperspektiven 2050+, it is now acknowledged that this subject must be considered.
- Two new technologies that can generate in principle negative emissions have gained momentum, namely pyrolysis of wood (PyCCS) and the use of wood as construction material that binds CO2 at least during the lifetime of the building (TCCS, timber CCS).
- Discussions with practitioners in the field revealed a strong hesitation to embark on completely new routes such as the gasification of wood to generate synthetic methane or even hydrogen. Such technology appeared very favourable in the scenario analysis of the JASM project. However, a reasonable sized gasification plant may need a wood supply from a radius that is significantly larger than the 50 km that are generally considered practical.

Due to these reasons we suggest to restructure WP12 and to augment it with a new Task 12.0 that focuses on the creation of scenarios for a net-zero Switzerland in 2050, characterizes the role of negative emission technologies for reaching this objectives and derives priorities for the next steps in WP12.

<u>New Task 12.0: First assessment of the value of NET technologies for reaching the objective of net-zero greenhouse-gas emissions (Lead: ETHZ)</u>

We used an energy system model to assess how the net-zero GHG emission goal can be achieved in a cost-optimal way. The model considers all energy forms and decarbonisation options (e.g. e-mobility, heat pumps, photovoltaics, storage), however, the results were analysed with regards to the value of negative emission technologies, which allow to permanently extract CO2 from the atmosphere (see deliverable report D12.0.1).

The main insight is that the net-zero goal cannot be achieved without underground CO2 storage. Depending on the scenario, an amount of 20-30 MtCO2/a needs to be stored. According to our current best knowledge it is unlikely that such volumes can be found in Switzerland, therefore we should support the creation of a European CO2 transport infrastructure that gives us access to storage sites in the North Sea or the Mediterranean.

The bulk of negative emissions can be created with thermal plants that burn a biogenic carbon containing fuel such as wood or waste. In Switzerland these are mainly the waste-to-energy plants, wood combined heat and power (CHP) plants and the cement plants. All these plants together can produce some 5 Mt/a of negative CO2 emissions. Besides the necessary CO2 transport infrastructure, the main challenge is the large energy demand for the CO2 separation facility. This energy is not available anymore for customers such as local utilities that run district heating networks. **A first priority should therefore be to execute detailed heat integration studies with plants from the aforementioned categories**. This is the subject of Task 12.3 reported below. The high relevance of this aspect could be confirmed in a series of workshops with plant operators (KVA Hinwil, KVA Perlen, HHKW Galgenen, Cement plant Wildegg).

A smaller amount of 2 Mt/a can be generated by improving the logistics of anaerobic digestion plants that generate biogas from green waste, sewage sludge or manure. Increasing the plant size by transporting the raw material to a central location could offer several advantages: (1) the bio-methane could be fed into in the gas grid, allowing to increase the biogas fraction for some scenarios to almost 20%; (2) the CO2 that has to be separated prior to gas injection could be fed into a CO2 pipeline network, generating some 1 Mt/a of negative emissions; (3) the digestate that remains after the anaerobic digestion process could be further processed by pyrolysis or hydrothermal gasification (depending on the water content), generating additional 1 Mt/a of negative emissions in the form of biochar. **The logistical aspects are key, therefore case studies with interested partners should be launched**. This is the subject of Task 12.2.

Last but not least, a large portion of negative emissions (5-10 Mt/a depending on scenario) can be generated with direct air capture (DAC). Here the energy requirement is even larger, requiring probably a co-location of DAC facilities with thermal plants. Besides the same challenge that this thermal energy cannot be sold to customers anymore, aspects such a space requirement must be understood in detail. **This requires heat integration and design studies with Climeworks, the Swiss supplier of DAC technology.** This is the subject of Task T12.4.

Despite the large theoretical value of gasification technologies for generating negative emissions, we suggest to de-prioritize this activity (Task 12.1).

Task 12.1 CO2-negative hydrogen production through gasification (Lead ETHZ)

As explained before, this task is given a lower priority. Progress in the field will be monitored by following projects with a similar focus as the Innosuisse Flagship DeCIRRA[12]. An ongoing study on the value of sustainable fuel production will also consider biomass-to-liquid as an option that is essentially a gasification technology with a subsequent Fischer-Tropsch synthesis (VADER[13]).

[12] https://www.innosuisse.ch/inno/de/home/forderung-fur-schweizer-projekte/flagship-initiative/15-flagships.html

[13] https://www.aramis.admin.ch/Grunddaten/?ProjectID=51133

Task 12.2 CO2-negative emissions through biological processes (Lead ETHZ)

The scenario analysis in T12.0 revealed a significant potential related to biological processes that often start with an anaerobic digestion of wet biomass (green waste, sewage sludge, manure). Practical logistical problems limit this potential, namely the small size of such installations that often does not allow for a connection to a natural gas grid, and to a future CO2-collection network. A large opportunity is related to the use of digestate, i.e. the residuals of anaerobic digestion that normally contain still significant amounts of biogenic carbon. Technologies such as hydrothermal carbonation (HTC) may allow to fix the carbon in a chemically stable form while maintaining the nutrients. Collaborations are sought with the ZHAW in Wädenswil on HTC and with WSL on the logistics of wet biomass processing.

Task 12.3 Post-combustion capture on an industrial plant

Switzerland has set itself the goal of reducing greenhouse gas emissions to net zero by 2050. The net zero target can only be achieved if CO_2 is captured from either point sources or from the atmosphere and stored permanently (so-called negative emissions). The work of HSLU-TEVT in Task 12.3 investigates CO_2 capture in a wood-fired power plant using an absorption plant with monoethanolamine (MEA) as solvent. The investigation considers techno-economic aspects of the integration and operation of the whole system.

In a first step, the considered wood-fired power plant and the expected process heat and district heating annual curves were analyzed (Figure 3). Over the year, a large part of the thermal energy remains unused and must be recooled. This thermal energy is to be used for the operation of the CO2 absorption plant. Different parameters were analysed to understand how the heat flows and power generation change over the year that are necessary for designing the CO_2 capture process and its integration. Figure 3(a) shows the annual heat flow and power demand of the wood-fired power plant with an exemplary district heating demand of a maximum of 12.5 MW. A considerable amount of energy (53.1 GWh/a) has to be recooled, especially in summer, as shown in dark grey. Figure 3(b) shows the effect of using the excess heat flow from the power plant in the CO_2 capture plant.

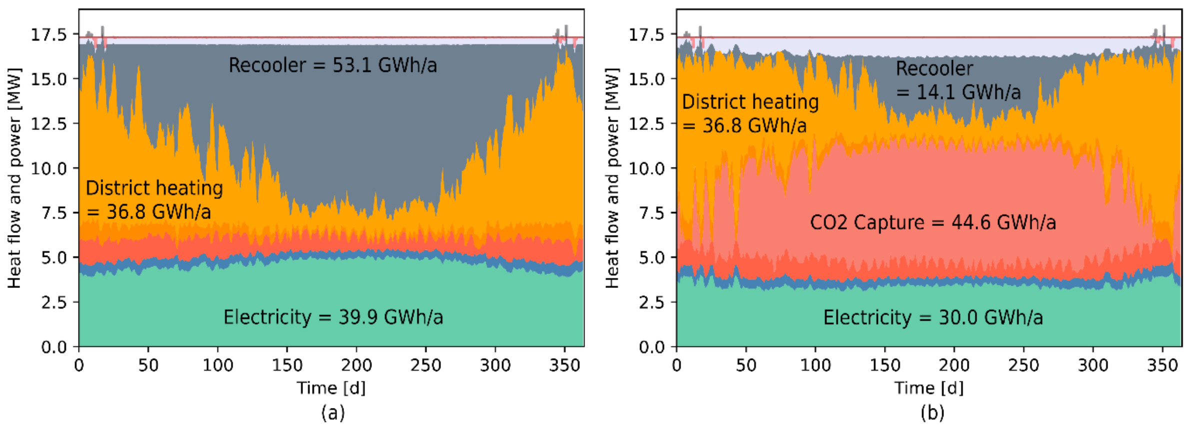


Figure 3: Energy use of the wood-fired power plant with district heating demand (a) without CO_2 capture plant, and (b) with CO_2 capture. Only the main energy flows are indicated (green: electricity; light orange: district heating; pink: CO_2 Capture; dark grey: recooler). The remaining heat flows are air preheating (blue), process heat at 140°C (red), additional process heat at 95°C (dark orange) and losses (light grey).

Three scenarios are considered to determine the CO_2 absorption plant size. The scenarios treat the total amount of flue gas produced (100%), as well as 65% and 30% of the flue gas. In these cases, the heat flow transferred to the CO_2 desorber ranges from 2.6 MW to 6.6 MW. The CO_2 absorption plant was modeled in the CHEMCAD simulation software and validated against literature values. A first simulation model is based only on the vapor-liquid equilibrium model. Using a multiple step procedure, the optimal operating parameters of the plant were determined, and different process optimization variants were tested to increase the energy efficiency. The potential energy savings amount to 9%. Given that the thermal power available to the CO_2 absorption plant varies depending on the process heat and district heating requirements, the operating ranges that enable stable plant operation must be evaluated. Therefore, a second simulation model that also considers mass transfer was conducted. These simulation results were used to establish the operating ranges of the different plant sizes as well as to determine the investment and operating costs based on this operating data. The results show the larger the CO_2 absorption plant, the larger its operating range. Annual operating data could be calculated based on the simulation data along with the annual curves show in Figure 3. The captured amount of CO_2 varies between 13'100 tons of CO_2 up to 33'000 tons of CO_2 depending on the plant size. These amounts correspond to a percentage capture of the total emitted CO_2 of 22 - 53% as shown in Figure 4.

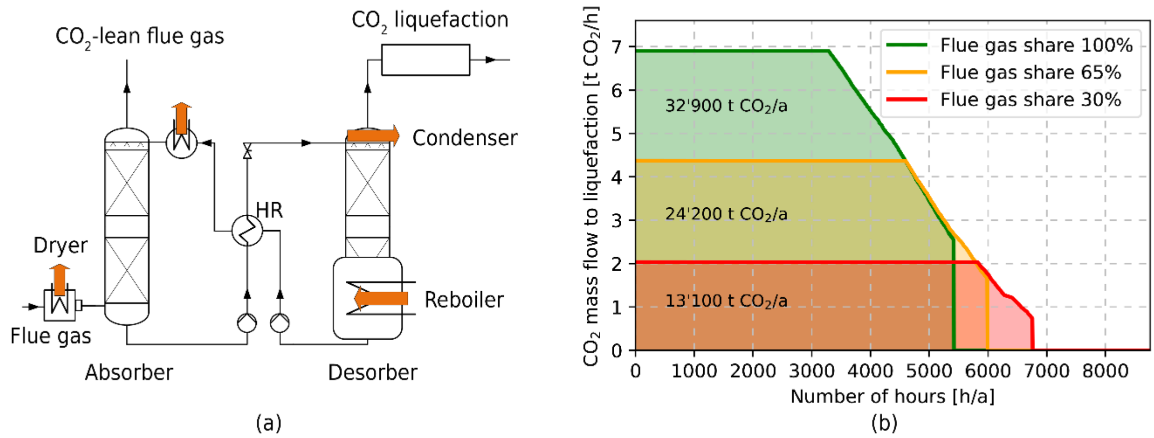


Figure 4. a) Simplified process flow diagram of the CO_2 absorption plant with indicated heat flows and b) the annual duration curves of the captured CO_2 mass flow and the resulting total amount of captured CO_2 per year depending on the plant size.

In a techno-economic comparison, the annualized costs of the CO2 capture plant can be calculated. The specific costs for CO_2 capture are about 136 CHF per ton. The further consideration of transport as well as final storage proved to be essential in the analysis. Depending on the considered scenario, the costs for CO_2 capture, liquefaction, transport, and final storage per ton of CO_2 amount to 185 - 261 CHF. A further sensitivity analysis identified other important boundary conditions and their effects. The results confirm that the development of the CO_2 and electricity prices in the future as well as the development of the political framework conditions and policy will determine the economic success of CO_2 capture in the considered wood-fired power plant. Note that the much simpler energy system analysis performed in T12.0 came to CO_2 avoidance costs from a waste-to-energy plant in the similar order of 150-200 CHF/t_{CO2}.

Task 12.4: Direct air capture and storage (Lead ETHZ)

The scenario analysis executed within Task 12.0 revealed the essential role of Direct Air Capture (DAC) for reaching the net-zero goal. It is clear that DAC will always be more expensive and energy intensive than the separation of CO2 from a point source such as a waste-to-energy plant or a cement plant. Therefore, it is only used for later stages when approaching net-zero. There is however a clear advantage of DAC. The separation from point sources requires obviously the proximity to the point source, and in addition the access to heat for the separation process and a CO2 infrastructure for connecting to a storage site. DAC can be placed right at the storage site, CO2 from the air is always available and the only requirement is access to energy for the separation process.

While our analysis indicates that DAC is needed, it is not said that such installation must be placed in Switzerland. Therefore a design study shall be launched with Climeworks, the Swiss supplier of DAC technology to understand the space demand and integration options of a DAC plant in Switzerland.

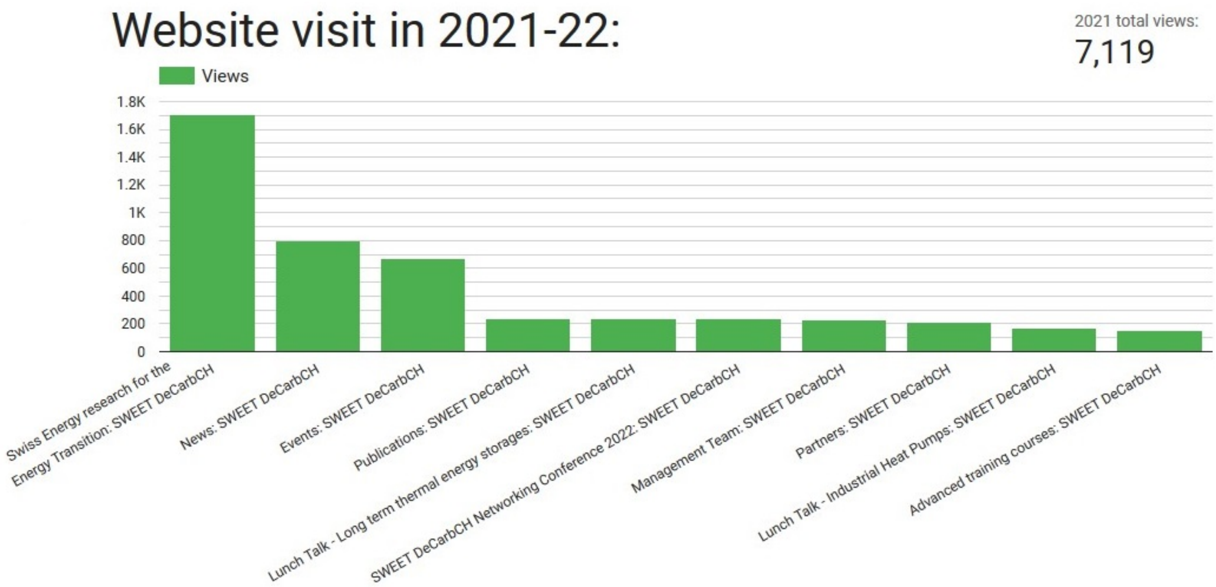
3.9 Knowledge and technology transfer

WP leader	*Cordin Arpagaus, OST-IES*
Members and coop. partners	*Cordin Arpagaus & Frédéric Bless, OST-IES*

Work performed and results

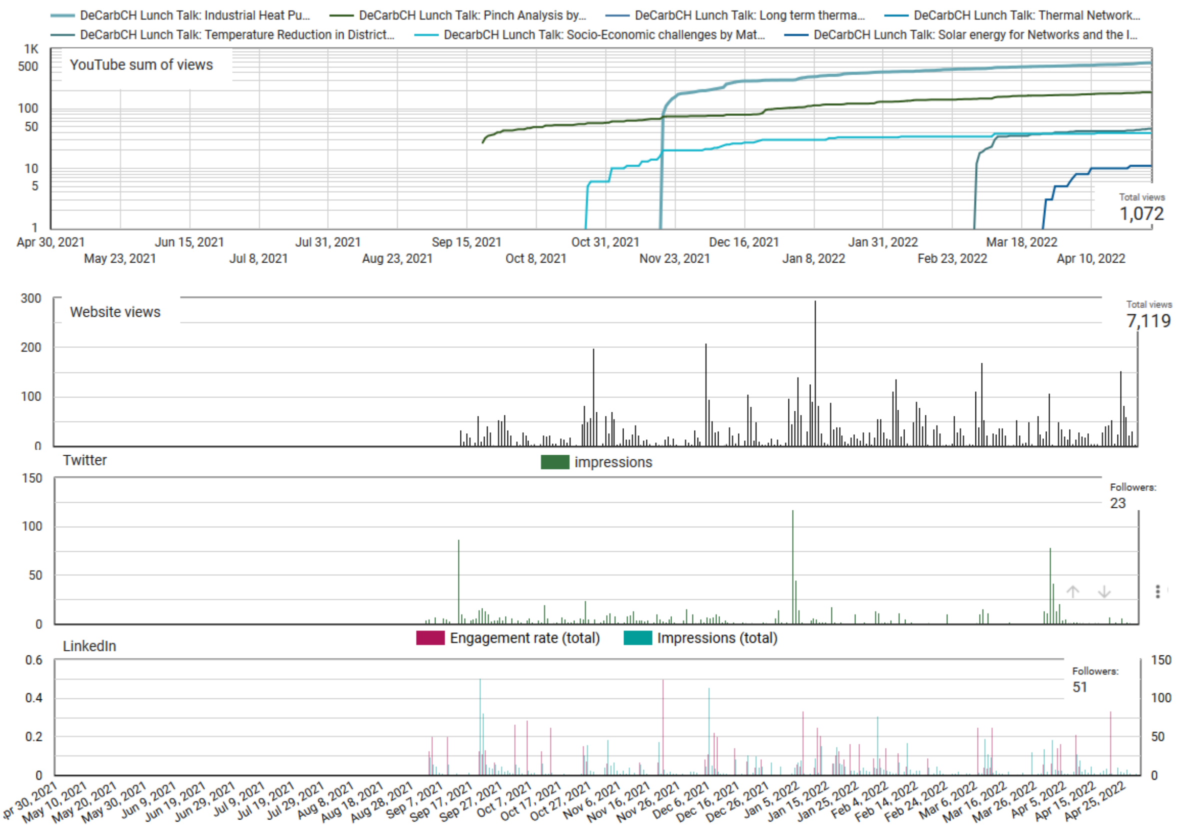
Website

The SWEET DeCarbCH Website (**www.sweet-decarb.ch**) was created and went online on the 1st of September 2022. The next figure illustrates the Website visits in 2021-22 with a total of 7’119 views. The most views on the webpages were the Main Page, News, and Events.



Accounts on Twitter, LinkedIn, and YouTube were created. The figures show the statistics of views as a function of time. In total there were 1’072 views on the YouTube Channel and 7’119 Website views. On Twitter there are 23 followers and on LinkedIn 51 followers.

SWEET DeCarbCH Online Timeline Statistic for 2021-22



<u>Lunch Talks</u>

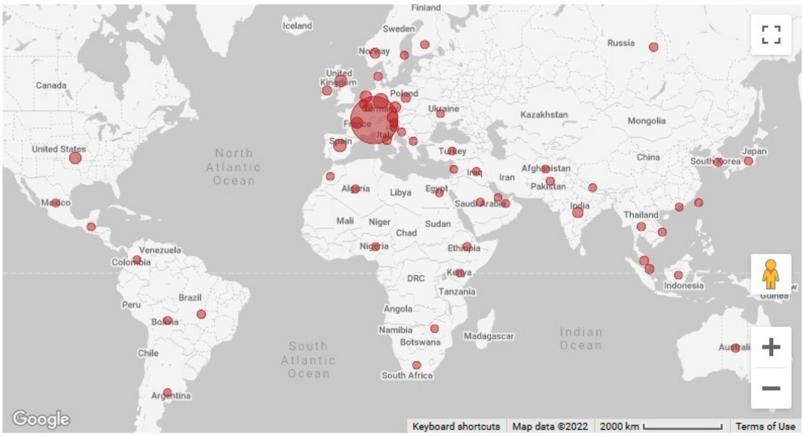
The team of DeCarbCH organized monthly Lunch Talks of about 30 to 45 minutes online via Zoom. The next table shows the topics and presenters. The Lunch Talks were recorded, cut into videos, and published on the DeCarbCH YouTube channel. The presentation slides are available for download from the Website.

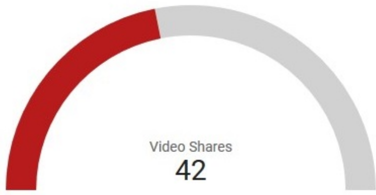
Title	Date	Presenter
Case Study City of Zurich	07.06.2022	Armin Eberle (ZHAW)
Negative Emission Technologies	10.05.2022	Gianfranco Guidati (ETHZ)
Perspectives on Thermal Grid Modelling under Uncertainty	05.04.2022	Jonathan Chambers (UNIGE)
Solar energy for Networks and the Industry	15.03.2022	Florian Ruesch (OST-SPF)
Temperature Reduction in District Heating	08.02.2022	Stefan Schneider (UNIGE)
Long-term Thermal Energy Storages	18.01.2022	Jörg Worlitschek (HSLU-TES)
Thermal Networks – Challenges and Outlook	07.12.2021	Tobias Sommer (HSLU)
Industrial Heat Pumps	09.11.2021	Cordin Arpagaus (OST-IES)
Socio-economic challenges	05.10.2021	Matthias Speich (ZHAW)
Pinch Analysis	09.09.2021	Donald Olsen (HSLU-TEV)

The next table illustrates the number of views per Lunch Talk on the YouTube channel. The views statistics show that the Lunch Talks were well received. For example, there were 583 views on the talk on Industrial Heat Pumps, 187 views on Pinch Analysis, and 134 views of the talk on Long-term Thermal Energy Storage.

SWEET DeCarbCH YouTube 2021-22 Statistic

	Video Title	Total Watch Time	Average Watch Time	Views	Video Shares
1.	DeCarbCH Lunch Talk: Industrial Heat Pumps presented by Cordin Arpagaus	65:47:27	00:06:46	583	20
2.	DeCarbCH Lunch Talk: Pinch Analysis by Donald Olsen	12:21:27	00:03:57	187	6
3.	DeCarbCH Lunch Talk: Long term thermal energy storages by Jörg Worlitschek	11:14:13	00:05:01	134	2
4.	DeCarbCH Lunch Talk: Thermal Networks – Challenges and Outlook presented by Tobias Sommer	06:24:41	00:05:20	72	5
5.	DeCarbCH Lunch Talk: Temperature Reduction in District Heating by Sefan Schneider	03:44:12	00:04:52	46	1
6.	DeCarbCH Lunch Talk: Solar energy for Networks and the Industry , presentation by Florian Ruesch	01:34:40	00:08:36	11	0
7.	DecarbCH Lunch Talk: Socio-Economic challenges by Matthias Speich	01:01:29	00:01:34	39	8
	Grand total	**102:08:13**	**00:05:42**	**1,072**	**42**





SWEET DeCarbCH Networking Conference 2022

On 25/26 April 2022 the DeCarbCH Networking Conference 2022 took place at the Seminar Zentrum Campus Sursee. There were 40 participants and a feedback survey revealed that the conference was well received. It was the first occasion to present the research findings of the SWEET DeCarbCH project in more detail and share knowledge with the DeCarbCH cooperation partners about the real problems and issues that are currently impeding the smooth and rapid decarbonisation of heating and cooling in the various sectors. The second day was for DeCarbCH researchers only for discussions within each work package. The main presentations are available online (Thermal Grids, Industry, Case Studies).

Newsletters

So far, 5 Newsletters have been sent out with a time interval of two months. Each newsletter focussed on a specific Work Package starting with WP1 and planned to WP7 until the end of 2022. Per Newsletter there was an interview with the WP leader with questions/answers and at least 6 to 8 News contributions, which were also posted on the Website (https://www.sweet-decarb.ch/news). Up to date, there have been 47 news contributions posted on the Website. The language of communication is English. The Newsletters covered many topics like:

- General News from all Work Packages
- News from the SWEET Office
- Technological highlights
- Special equipment that has been installed
- Invitations to Lunch Talks

- Invitations to Annual Conferences
- Links to YouTube videos and presentation downloads
- Survey results
- Interviews with WP leaders
- Invitations to DeCarbCH-related events, e.g., district heating workshop
- New publications, e.g., journal articles, technical reports, white papers

Title	Publication date	Work Package focus	Main topic	Status
September 2021	07.09.2021	Project start	Introduction of DeCarbCH Website	Done
November 2021	02.11.2021	WP1	Mesoscale modelling	Done
January 2022	13.01.2022	WP2	Socio-economic & legal	Done
March 2022	09.03.2022	WP3	Technology: Thermal grid	Done
May 2022	13.05.2022	WP4	Energy demand profiles of industries	Done
July 2022	*04.07.2022*	*WP5*	*Technology: HT heating & cooling*	*Planned*
September 2022	*05.09.2022*	*WP6*	*Case Study: City of Zurich*	*Planned*
November 2022	*07.11.2022*	*WP7*	*Case Studies: Romandie district heating*	*Planned*

4 Outreach & outputs during the reporting period

Peer-reviewed publications

Members and coop. partners	**Description:** author(s), title, journal or type of publication, year of publication	doi
ZHAW-ZOW	Beatrix Schibli, Biomasseanlagen in der Landwirtschaft, SzE – Schriften zum Energierecht, Band 20, 2022	https://doi.org/10.3256/978-3-03929-014-7
ZHAW-ZOW	Beatrix Schibli, Solarstrom und Direktzahlungsberechtigung mit Fokus auf Photovoltaik-Anlagen, SzE – Schriften zum Energierecht, Band 24, 2022	https://doi.org/10.3256/978-3-03929-019-2
ZHAW-ZOW	Andreas Abegg/Nagihan Musliu, Die Fernwärmeversorgung – eine rechtliche Einordnung, sui generis 2022, pp. 43-52	https://doi.org/10.21257/sg.203
ZHAW-INE	Hafner, S., Speich, M., Bischofberger, P. and Ulli-Beer, S.: Governing Industry decarbonisation: policy implications from a firm perspective. Under review for *Journal of Cleaner Production*.	Forthcoming
ZHAW-INE	Speich, M. and Ulli-Beer, S.: Alignment of ecosystems in low-carbon energy transitions: A conceptual model of long-term value creation. Under review for *Journal of Cleaner Production*.	Forthcoming
UNIGE-EE	Walch, A., Li, X., Chambers, J., Mohajeri, N., Yilmaz, S., Patel, M.; Scartezzini, J.-L.: “Shallow Geothermal energy potential for heating and cooling of buildings with regeneration under climate change scenarios.” Energy 244 (2022), pp.15	https://doi.org/10.1016/j.energy.2021.123086
UNIGE-EE	Li, X. Walch, A. Yilmaz, S. Patel, M. Chambers, J. “Optimal spatial resource allocation in networks: application to district heating and cooling” Computers & Industrial Engineering 2022	https://doi.org/10.1016/j.cie.2022.108448
HSLU	M. Berger, B. Schroeteler, H. Sperle, P. Püntener, T. Felder, J. Worlitschek; Assessment of residential scale renewable heating solutions with thermal energy storages; Energy, 122618; 2021	https://doi.org/10.1016/j.energy.2021.122618
ETHZ, ZHAW	Tzinnis, Efstratios; Baldini, Luca, 2021. Combining sorption storage and electric heat pumps to foster integration of solar in buildings. Applied Energy. 301(117455).	https://doi.org/10.1016/j.apenergy.2021.117455
Empa, ZHAW	Fiorentini, Massimo; Baldini, Luca, 2021. Control-oriented modelling and operational optimization of a borehole thermal energy storage. Applied Thermal Engineering. 199(117518).	https://doi.org/10.1016/j.applthermaleng.2021.117518
Empa, ZHAW	Fiorentini, M., Vivian, J., Heer, P., Baldini, L. Design and optimal integration of seasonal borehole thermal energy storage in district	https://doi.org/10.34641/clima.2022.64

	heating and cooling networks. CLIMA 2022: the 14th REHVA HVAC World Congress 22nd - 25th May. Rotterdam, Netherlands, 2022.	
SUPSI	Toffanin, R.; Caputo, P.; Belliardi, M.; Curti, V. Low and Ultra-Low Temperature District Heating Equipped by Heat Pumps—An Analysis of the Best Operative Conditions for a Swiss Case Study. Energies 2022.	https://doi.org/10.3390/en15093344
HSLU-TEVT	Jan A Stampfli, Benjamin HY Ong, Donald G Olsen, Beat Wellig, René Hofmann, Applied heat exchanger network retrofit for multi-period processes in industry: A hybrid evolutionary algorithm, Computers & Chemical Engineering, 2022	*https://doi.org/10.1016/j.compchemeng.2022.107771*
HSLU-TEVT	Jan A Stampfli, Donald G Olsen, Beat Wellig, René Hofmann, A parallelized hybrid genetic algorithm with differential evolution for heat exchanger network retrofit, MethodsX, 2022	*https://doi.org/10.1016/j.mex.2022.101711*
HSLU-TEVT	Raphael Agner, Benjamin HY Ong, Jan A Stampfli, Pierre Krummenacher, Beat Wellig, A Graphical Method for Combined Heat Pump and Indirect Heat Recovery Integration, Energies, 2022	*https://doi.org/10.3390/en15082829*
HSLU-TEVT	Benjamin HY Ong, Edward J Lucas, Donald G Olsen, Simon Roth, Beat Wellig, A user workflow for combining process simulation and pinch analysis considering ecological factors, Chemical Product and Process Modelling, 2021	*https://doi.org/10.1515/cppm-2021-0004*

Policy briefs, white papers

Members and coop. partners	**Description:** author(s), title, channel or type of publication, year of publication
HSLU, ZHAW-ZBP, ETHZ, OST	Guidati, F., Worlitschek, J., Baldini, L., Haller, M.: Winterstrombedarf und saisonale Wärmespeicher – mit Sommerwärme Strom im Winter sparen; Forum Energiespeicher Schweiz; 2022
ZHAW-ZBP, A+W, OST	Baldini, L., Braendle, S., Haller, M., Schlegel, M. Zu jeder Raumplanung gehört auch eine Energierichtplanung. Forum Energiespeicher, AEE Suisse, Januar, 2022.

Other non-peer-reviewed publications (working papers, press articles, conference papers, etc.)

Members and coop. partners	**Description:** author(s), title, channel or type of publication, year of publication
OST-IES	Bless F., Speich M., Arpagaus C., Bertsch S.S., Electrification of heat generation in industry: technologies, integration and barriers, Young Energy Researchers Conference, 5 April, 2022, Wels, Austria
OST-IES	Arpagaus, C., Bless, F., Bertsch, S.S., Techno-Economic Analysis of Steam-Generating Heat Pumps in Distillation Processes, 3rd High-Temperature Heat Pump Symposium, 29-30 March, 2022, Copenhagen, Denmark
OST-IES	Arpagaus, C., Payá, J. Hassan, A.H., Bertsch, S.S.: Potential Impact of Industrial High-Temperature Heat Pumps on the European Market, 3rd High-Temperature Heat Pump Symposium, 29-30 March, 2022, Copenhagen, Denmark
OST-IES	Saini, P., Hedstrom, A., Arpagaus, C., Bless, F., Bertsch, S.: A hybrid system of steam generating heat pump and solar parabolic trough collectors for process heating: Techno-economic analysis for a brewery, 3rd High-Temperature Heat Pump Symposium, 29-30 March, 2022, Copenhagen, Denmark
OST-IES	Längauer, A.; Adler, B; Arpagaus, C.; Bless, F.; Bertsch, S.: Vergleich der Rotationswärmepumpe mit konventionellen Kompressionswärmepumpen in industriellen Prozessen, DKV Tagung 2021, 17.-19. November 2021, Dresden.
HSLU-TEVT	Raphael Agner, Benjamin HY Ong, Jan A Stampfli, Pierre Krummenacher, Beat Wellig, Practical integration of heat pumps with thermal energy storage in non-continuous processes, 24th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction, Brno, Czech Republic, Oct. 31 - Nov. 3, 2021
HSLU-TEVT	Jan A Stampfli, Benjamin HY Ong, Donald G Olsen, Beat Wellig, René Hofmann, A hybrid evolutionary algorithm for heat exchanger network retrofit for processes with multiple operating cases, 16th Conference on Sustainable Development of Energy, Water and Environment Systems, Oct. 10-15, 2021
HSLU-TEVT	Beat Wellig, Raphael Agner, Benjamin HY Ong, Jan A Stampfli, Donald G. Olsen, Pierre Krummenacher, Integration von Wärmepumpen und Speichern zur Effizienzsteigerung nicht-kontinuierlicher Prozesse, 27. Tagung des Forschungsprogramms ‘Wärmepumpen und Kältetechnik’ des Bundesamtes für Energie BFE, Burgdorf 23. Juni 2021

Public oral and visual presentations (scientific or broad audience)

Members and coop. partners	**Description:** author(s), title, name of the event and location, year of presentation
ZHAW-INE	Speich, M. and Ulli-Beer, S.: Neue Chancen der Wertschöpfung im Zuge der Dekarbonisierung von Wärme und Kälte: Poster presentation, WinLab, Winterthur, September 28, 2021
ZHAW-INE	Speich, M., Hafner, S., Bischofberger, P., Ulli-Beer, S: Umsetzung von Dekarbonisierungsmassnahmen in der Industrie: eine Unternehmensperspektive. Oral presentation, Energieforschungsgespräche Disentis, January 27 2022.
ZHAW-INE	Speich, M., and Ulli-Beer, S.: Digitale Ressourcen im Ökosystem der Energiewende. Poster presentation, Powertage, Zürich, May 17, 2022.
OST-IES	Arpagaus, C.: Industrial Heat Pumps: Research and Market Update, Australian Alliance for Energy Productivity (A2PH) Webinar: High temperature heating solutions, November 10, 2021
OST-IES	Arpagaus, C.: Hochtemperatur-Wärmepumpen: Potenziale und Einsatzmöglichkeiten für die Bereitstellung von Prozesswärme in der Industrie, VEA-Veranstaltung: Wie die Dekarbonisierung gelingen kann: Einsatz alternativer Energien und Technologien im Unternehmen, 5. April 2022, Online Seminar
OST-IES	Arpagaus, C.: Industrial Heat Pumps: Research and Market Update, Webinar American Council for an Energy-Efficient Economy (ACEEE): Electrifying Industry's Process Heat Supply with Industrial Heat Pumps, It's Time to Electrify Industry's Process Heat—with Heat Pumps | ACEEE, April 6, 2022
	Bertsch, St.: Dekarbonisierung der Industrie durch Prozessintegration und Wärmepumpen: 20. Ostschweizer Technologie Symposium, St. Gallen, 2021
HSLU	Philipp Schütz; Data-based assessment of retrofitting measures; March 2022
HSLU	Philipp Schütz: Beispiele Energieforschung an der HSLU; general assembly of NELU; March 2022
ZHAW-INE	Speich, M., Hafner, S., Bischofberger, P., Ulli-Beer, S: Umsetzung von Dekarbonisierungsmassnahmen in der Industrie: eine Unternehmensperspektive. Oral presentation, Energieforschungsgespräche Disentis, January 27 2022.
UNIGE-EE, OST-SPF	Conference presentation: J. Chambers and M. Rittman-Frank. "Presentation of new geospatial datasets for renewable thermal energy systems modelling in Switzerland", CISBAT, Lausanne, 2021
HSLU	Worlitschek J.; Saisonale Wärmespeicher sollen bei Energiewende helfen; Tagesschau SRF1; May 30, 2022
HSLU	William Delgado: Hybrid PCM-Storages for SFH and MFH, IEA-SHC Swiss National Research Day, Rapperswil 2022
OST-SPF	Florian Ruesch: Thermal Storages for Swiss District Heating Systems, IEA-SHC Swiss National Research Day, Rapperswil 2022
OST-SPF	Florian Ruesch: Solarwärme und Erdwärmesonden – Einsatz in Anergienetzen, Zusammenhänge und Beispiele, connect4geothermal, Biel 2021
OST-SPF	Mercedes Rittmann & Florian Ruesch: Solare Grossanlagen für Wärmenetze und Industrie, Energieapéro beider Basel, Muttenz 2021
OST-SPF	Florian Ruesch: Wärmenetze mit Holz und Solarthermie, Swissolar Solarwärme-Tagung, Hedingen, 2021

HSLU-TEVT	Raphael Agner, Benjamin HY Ong, Jan A Stampfli, Pierre Krummenacher, Beat Wellig, Practical integration of heat pumps with thermal energy storage in non-continuous processes, 24th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction, Brno, Czech Republic, Oct. 31 - Nov. 3, 2021
HSLU-TEVT	Jan A Stampfli, Benjamin HY Ong, Donald G Olsen, Beat Wellig, René Hofmann, A hybrid evolutionary algorithm for heat exchanger network retrofit for processes with multiple operating cases, 16th Conference on Sustainable Development of Energy, Water and Environment Systems, Oct. 10-15, 2021
HSLU-TEVT	Beat Wellig, Raphael Agner, Benjamin HY Ong, Jan A Stampfli, Donald G. Olsen, Pierre Krummenacher, Integration von Wärmepumpen und Speichern zur Effizienzsteigerung nicht-kontinuierlicher Prozesse, 27. Tagung des Forschungsprogramms 'Wärmepumpen und Kältetechnik' des Bundesamtes für Energie BFE, Burgdorf 23. Juni 2021
HSLU, UNIGE, OST, ZHAW	Status updates at DeCarbCH Networking Conference, 25-26 April 2022: • Willy Villasmil, Tobias Sommer, Jonathan Chambers. Thermal networks • Beat Wellig, Stefan Bertsch. Industry • Armin Eberle, Pierre Hollmuller. Case studies • Matthias Speich, Silvia Ulli-Beer, Beatrix Schibli, Reto Walther, Andreas Abegg. Legal and socio-economic • Adriana Marcucci, Selin Yilmaz, Martin Neugebauer, SWEET-CROSS **https://www.sweet-decarb.ch/events/event/sweet-decarbch-networking-conference-2022**
All partners	Lunch talks: (see table below) **https://www.youtube.com/channel/UCAS1Pq0TY_id1DlwT-5rKzg**

Lunch talks:

Case Study City of Zurich	07.06.2022	Armin Eberle (ZHAW)
Negative Emission Technologies	10.05.2022	Gianfranco Guidati (ETHZ)
Perspectives on Thermal Grid Modelling under Uncertainty	05.04.2022	Jonathan Chambers (UNIGE)
Solar energy for Networks and the Industry	15.03.2022	Florian Ruesch (OST-SPF)
Temperature Reduction in District Heating	08.02.2022	Stefan Schneider (UNIGE)
Long-term Thermal Energy Storages	18.01.2022	Jörg Worlitschek (HSLU-TES)
Thermal Networks – Challenges and Outlook	07.12.2021	Tobias Sommer (HSLU)
Industrial Heat Pumps	09.11.2021	Cordin Arpagaus (OST-IES)
Socio-economic challenges	05.10.2021	Matthias Speich (ZHAW)
Pinch Analysis	09.09.2021	Donald Olsen (HSLU-TEV)

Completed theses

Members and coop. partners	**Description:** author(s), title, type (master, PhD), year
ZHAW-INE	P. Bischofberger: *DecarPro – Studie zu Hindernissen und Treibern zur Dekarbonisierung von industriellen Prozessen*. Semester project, December 2021.
ZHAW-INE	D. Edathinakam and P. Bischofberger: *DeCarb Industry –Roadmap zur Dekarbonisierung der Lebensmittelindustrie*. BSc Thesis, June 2022
HSLU-TEVT	Mario Bucher, Multi-objective Optimisation of Thermal Networks, Master Thesis, HSLU-TEVT, 2022

Patent applications and awarded patents

Members and coop. partners	**Description:** inventor(s), title, priority date, patent exploited, status, validity, brief description
HSLU-TES	Cowa Thermal Solutions AG; Wärmespeicherkapsel mit einem Phasenwechselmaterial; applied for patent; 06.2021

Licences

Members and coop. partners	**Description:** subject, grantor of license, license holder, year, contract period, brief description
HSLU-TEVT	PinCH Software, HSLU, HSLU, 2021, Leasing and Purchase models, Software to support application of Pinch Analysis in industry

Spin-offs

Members and coop. partners	**Description:** name of spin-off company, founder, year of incorporation, town, brief description of the business idea

Other outputs

Members and coop. partners	**Description**: brief description of the outputs.
ETHZ, UNIGE-EE, OST-SPF	Online data platform: https://sweet-cross.ch/data/
HSLU-TEVT	Energy Optimization with Pinch Analysis course in German and English in 2021. The course teaches the theoretical and practical application of Pinch Analysis to examine energy use in industrial companies and how to systematically develop specific measures to increase efficiency, to optimize the utility systems, and to integrate renewables.
HSLU-TEVT	Individual coaching of professionals from engineering firms and industrial companies on topic of Energy Optimization with Pinch Analysis. In the reporting period, the coaching was conducted for Altana AG (Germany/Texas, US), Lemon Consult AG, e.Luterbach AG, and Croda Europe Ltd..

Final reports

WP n°	**Members and coop. partners**	**ARAMIS link**
WP3	Empa	**https://www.aramis.admin.ch/Texte/?ProjectID=45284**
WP1	OST-SPF HSLU-TEVT	BILLY SOLAR – Reduction of CO2 emissions through integration of scalable and cost-effective modular solar process heat units https://www.aramis.admin.ch/Beteiligte/?ProjectID=44254
WP5	HSLU-TEVT	Integration of Heat Pumps and Thermal Energy Storages in Non-Continuous Industrial Processes, HPTES, *status: Final report revision submitted.*

5 Updated list of consortium members and cooperation partners

Table 5-1: List of consortium members

Additional members					*10a*		
Previous members (no longer part of the consortium)							
N°	**Members** • Legal organisation's name • Group/laboratory • Name of the representative	**Short name**	**Type of organisation**	**Language region of CH**	**Canton or country**	**Expertise and contribution**	**Member in other SWEET consortia**
1	Université de Genève, Energy Efficiency, Martin Patel	UNIGE-EE	Cantonal university	French	Geneva	Energy savings and emission reduction in industry and the built environment	
2	Eidgenössische Material- und Prüfungsanstalt, Urban Energy Systems, Kristina Orehounig	EMPA	Federal research institute	German	Zürich	Development of sustainable concepts in building design and operation, integration of renewable energy systems, simulation and optimization of buildings and urban energy systems	PATHFNDR
3	Eidgenössische Technische Hochschule Zürich, Energy Science Center, Gianfranco Guidati	ETHZ	Federal university	German	Zürich	Energy system modelling	PATHFNDR EDGE SURE
4	Hochschule Luzern, Building technology and Energy Willy Villasmil	HSLU-IGE	University of applied sciences	German	Luzern	Building Technology and Energy Research for carbon-free, energy-efficient and sustainable construction	PATHFNDR

5	Hochschule Luzern, Thermal Energy Storage, Jörg Worlitschek	HSLU-TES	University of applied sciences	German	Luzern	Thermal energy storage, phase change materials,integration of TES	
6	Hochschule Luzern, Thermal energy systems and process engineering, Beat Wellig	HSLU-TEVT	University of applied sciences	German	Luzern	Optimal heat integration in industrial processes, Pinch analysis	
7	OST Hochschule für Technik Buchs, Institute for Energy Systems, Stefan Bertsch	OST-IES	University of applied sciences	German	St. Gallen	Heat pump technology, integration in industrial processes	
8	OST Hochschule für Technik Rapperswil, Institute for Solar Technology, Andreas Häberle	OST-SPF	University of applied sciences	German	St. Gallen	Solar thermal technology, integration in industrial processes	
9	Zürcher Hochschule für Angewandte Wissenschaften, Armin Eberle	ZHAW-INE	University of applied sciences	German	Zürich	Development of smart and sustainable solutions for the transition of the energy and mobility system	
10	Zürcher Hochschule für Angewandte Wissenschaften, Andreas Abegg	ZHAW-ZOW	University of applied sciences	German	Zürich	Practice-oriented, interdisciplinary research projects concerning the diverse links between the state and the commercial sector	SURE
10a	Zürcher Hochschule für Angewandte Wissenschaften, Centre for Building Technologies and Processes, Luca Baldini	ZHAW-BEST	University of applied sciences	German	Zürich	Innovative technologies in the building sector	
11	Centre de Recherches Energétiques et Municipales, Jakob Ragers	CREM	Consultancy	French	Wallis	Support to public authorities and companies in their challenges related to energy and its network	

						infrastructures towards more sustainability.	
12	Haute Ecole d'Ingénierie et de Gestion du Canton de Vaud , Pierre Krummenacher	HEIG-VD	University of applied sciences	French	Waadt	Optimal heat integration in industrial processes, Pinch analysis	
13	Institut für Nachhaltigkeits- und Demokratiepolitik, Roman Bolliger	INDP	Consultancy	German	Luzern	Sustainable development at the level of communes, cities, regions and cantons	
14	Scuola universitaria professionale della Svizzera italiana, Vinicio Curti	SUPSI	University of applied sciences	Italian	Tessin	Mechanical Engineering and Materials Technology	SURE
15	Université de Genève, Geo-Energy / Reservoir Geology and Basin Analysis, Andrea Moscariello	UNIGE-GE	Cantonal university	French	Geneva	Geoenergy in sedimentary basins, underground thermal energy storage	
16	Université de Genève, Systèmes énergétiques Pierre Hollmuller	UNIGE-SE	Cantonal university	French	Geneva	Interdisciplinary research on energy systems and pathways, with a view to controlling demand, improving energy efficiency and integrating renewable energies.	

Table 5-2: List of cooperation partners

Additional cooperation partners				*52-56*		
Previous cooperation partners (no longer cooperating)				*Anex Ingenieure AG*		
N°	**Cooperation partner** • Legal organisation’s name • Group/laboratory • Name of the representative	**Short name**	**Type of organisation**	**Language region of CH**	**Canton or country**	**Expertise and contribution**
17	City of Zürich, Silvia Banfi-Frost	Stadt Zürich	City	German	Zürich	Transformation of city energy system, WP6
18	City of Winterthur, Michael Künzle	Stadt Winterthur	City	German	Winterthur	Transformation of city energy system, WP3
19	Swiss Solar Energy Professionals Association, Daniel Stickelberger	Swissolar	Association	German	Zürich	Solar potential and Technologies, WP1, 4, 5
20	Swiss District Heating Association (Verband Fernwärme Schweiz, L'Association suisse du chauffage à distance), Andreas Hurni	VFS/ASCAD	Association	German	Bern	District heating networks, WP3
21	Verband der Betreiber Schweizerischer Abfallverwertungsanlagen, Robin Quartier	VBSA	Association	German	Bern	Waste-to-energy plants, integration with district heating networks, CO2-separation, WP12
22	Verein für Abfallentsorgung Buchs, Urs Brunner	VfA Buchs	Public sector - Industrial	German	St. Gallen	Waste-to-energy plants, integration with district heating networks, WP3
23	Verband der Schweizerischen Gasindustrie, Daniela Decurtins	VSG	Association	German	Zürich	Gas grid infrastructure, WP12
24	Société coopérative de chauffage à distance à bois le Marais-Rouge, Didier Barth	CADB	Association	French	Neuchâtel	District heating networks, WP7
25	Energie-Agentur der Wirtschaft, Thomas Weisskopf	EnAW	Association	German	Zürich	Industrial energy demand, efficiency measures, WP4, WP5
26	energie-cluster.ch	energie-cluster	Association	German	Bern	Energy efficiency, decarbonisation, WP4, WP5
27	Services Industriels de Genève, Marcel Ruegg	SIG	Public sector - Urban	French	Geneva	Transformation of city energy system, WP7

28	energienetz GSG AG, St. Galler Stadtwerke, Simon Schoch	GSG	Private sector - Urban	German	St. Gallen	Transformation of city energy system, WP3
29	energie360° AG, Ruth Happersberger	e360	Private sector - Urban	German	Zürich	Transformation of city energy system, District heating networks, WP3
30	Energie Wasser Bern, Michael Samboni	ewb	Private sector - Urban	German	Bern	Transformation of city energy system, District heating networks, waste-to-energy plants, WP3
31	Abicht Zug AG, Daniel Kaufmann	Abicht	Private sector - Engineering Firm	German	Zug	Energy planning, district heating systems, WP3
32	Amstein + Walthert AG, Matthias Mast	A+W	Private sector - Engineering Firm	German	Zürich	Energy planning, district heating systems, WP3
34	eicher+pauli Olten AG, Andreas Grüniger	eicher+pauli	Private sector - Engineering Firm	German	Solothurn	Energy planning, district heating systems, WP3
35	Weisskopf Partner GmbH, Thomas Weisskopf	Weisskopf	Private sector - Engineering Firm	German	Zürich	Energy planning, WP3
36	Lauber IWISA AG, Sandro Werlen	Lauber	Private sector – Engineering firm	French	Wallis	Energy planning, district heating systems, WP3
37	INFRAS AG, Martin Soini	INFRAS	Private sector - Consultant	German	Zürich	Energy planning, district heating systems, WP3
38	Helbling Beratung + Bauplanung AG, Christian Bürgin	helbling	Private sector - Consultant	German	Zürich	Energy planning, district heating systems, WP3
39	BASF Schweiz AG, Olivier Enger	BASF	Private sector - Industrial	German	Basel	Industrial energy demand and supply, WP4, WP5
40	Juracime S.A, Christoph Veuve	Juracime	Private sector - Industrial	German	Neuchâtel	Cement production, WP3, WP12
41	Emmi Schweiz AG, Gerold Schatt	Emmi	Private sector - Industrial	German	Luzern	Industrial energy demand and supply, WP4, WP5

42	Coop Genossenschaft, Salome Hofer	Coop	Private sector - Industrial	German	Basel	Industrial energy demand and supply, WP4, WP5
43	Migros-Genossenschafts-Bund, Florian Brunner	MGB	Private sector - Industrial	German	Zürich	Industrial energy demand and supply, WP4, WP5
44	Feldschlösschen Supply Company AG, Thomas Janssen	Feldschlösschen	Private sector - Industrial	German	Aargau	Industrial energy demand and supply, WP4, WP5
45	Belimo Automation AG, Stefan Mischler	Belimo	Private sector - Industrial	German	Zürich	Industrial energy demand and supply, WP4, WP5
46	Sika Manufacturing AG, Reto Badertscher	Sika	Private sector - Industrial	German	Freiburg	Industrial energy demand and supply, WP4, WP5
47	Sefar AG, Christoph Ellenberger	Sefar	Private sector - Industrial	German	Appenzell	Industrial energy demand and supply, WP4, WP5
48	Cowa Thermal Solutions AG, Remo Waser	COWA	Private sector - Industrial	German	Luzern	Thermal energy storage technology, WP4, WP5
49	Schenk AG, Peter Schenk	Schenk	Private sector - Industrial	German	Thurgau	Horizontal drilling, thermal energy storage, WP3
50	Casale SA, Michal Bialkowski	Casale	Private sector - Industrial	Italian	Tessin	Chemical processes, CO2-separation, WP12
51	SBB AG, Daniel Fuhrer	SBB	Public sector - Transport	German	Bern	Logistics, transport of gases, WP12
52	Viteos, Yann Oberson	Viteos	Public sector - Urban	French	Neuchatel	District heating networks, WP3, WP7
53	Technische Betriebe Wil, Marco Huwiler	TBW	Public sector - Urban	German	St Gallen	District heating networks, WP3
54	Nestle, Vincent Grass	Nestle	Private sector - Industrial	French	Waadt	Industrial energy demand and supply, WP4, WP5
55	Danfoss, Drew Turner	Danfoss	Private sector - Industrial	German	Basel	Industrial energy demand and supply, WP4, WP5
56	Azienda Elettrica di Massagno, Daniele Farrace	AEM	Public sector - Urban	Italian	Tessin	District heating networks, WP3

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Stadt Zurich: Energieplankarte der Stadt Zürich (Energy plan map of the city of Zurich): https://www.stadt-zuerich.ch/dib/de/index/energieversorgung/energiebeauftragter/publikationen/energieplankarte-der-stadt-zuerich.html

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Appendix 2

No.	Title	Authors
D4.1.1	Development of Standardised Evaluation Framework for Industrial Data	Benjamin H. Y. Ong, HSLU-TEVT Beat Wellig, HSLU-TEVT
D12.0.1	First assessment of the value of NET technologies for reaching the objective of net-zero greenhouse-gas emissions	Gianfranco Guidati, ETHZ