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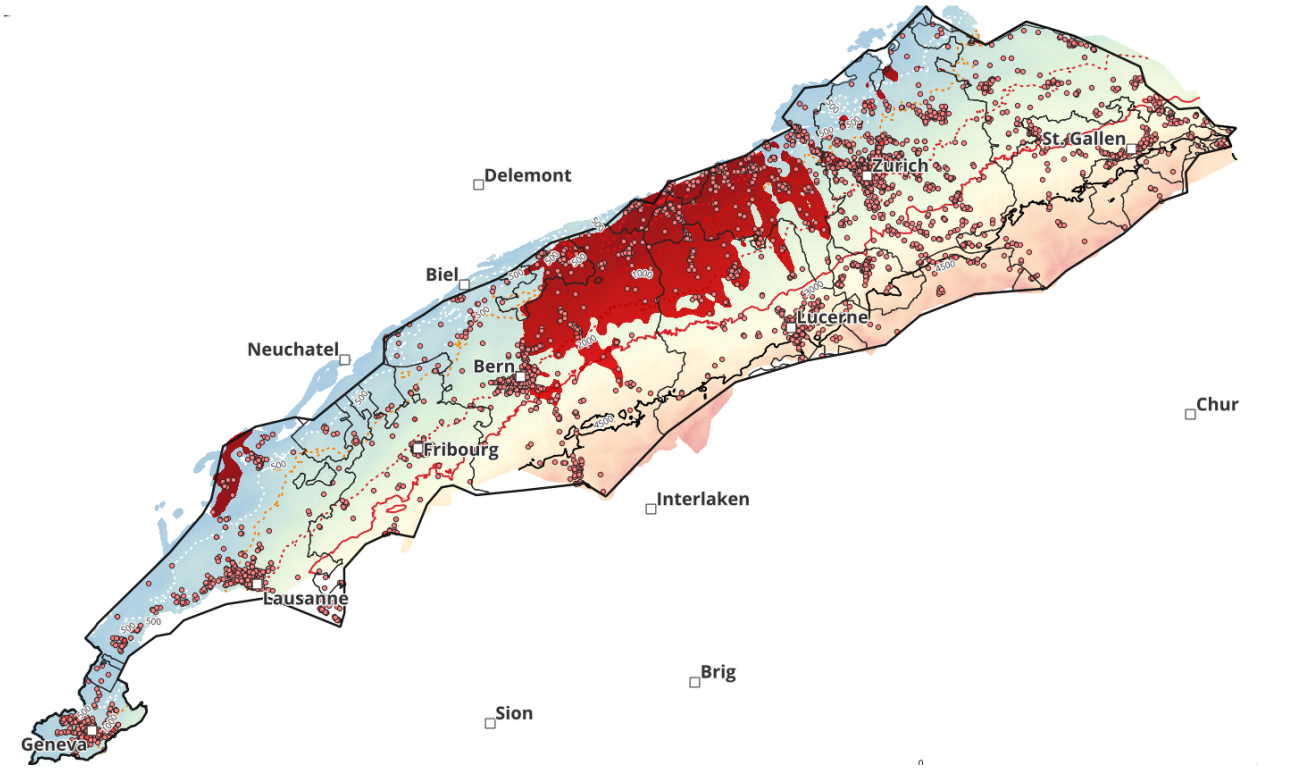
Highlights Report Year 3

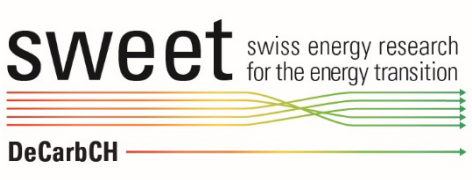
DeCarbCH



Area where subsurface temperatures reaches 70°C at 1500m deep, suitable for geothermal direct use coupled with location of high energy demands

Source: ©UNIGE 2024

sweet swiss energy research for the energy transition



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Highlights

The main highlights (results, challenges, learnings, etc.) during the reporting period were the following:

- There is significant potential for 5th generation district heating and cooling (5GDHC) networks, especially as cooling demand in the building sector will approach heating demand by mid-century. Key elements are a borehole heat storage, which is regenerated by cooling demand in summer, and heat pumps, which utilise this stored energy to provide space heating and hot water in winter. A P&D project with the municipality of Grandvaux (VD) is underway.
- Combined with innovative low-temperature methods of distributing the heat in the building, the electricity demand of heat pumps can be reduced. For Switzerland as a whole, the aforementioned innovations can reduce winter electricity demand by several TWh.
- While 5GDHC networks are the solution for the future, also today's existing high temperature networks can be optimized by reducing temperatures, significantly improving their efficiency in terms of heat generation and distribution losses. In the case of a 2nd generation district heating system in Geneva, a reduction of the current supply/return temperature regime of 110/70°C to 90/45°C allows to enhance the integration potential of renewable energies – especially geothermal – from 75% to 82%.
- In the industrial sector, the aim is to understand how much heat is required at what temperature. This reduces the electricity consumption of heat pumps and facilitates the integration of renewable low-temperature energy sources such as solar and geothermal. A methodology was developed to create company-wide energy demand profiles for various industries in Switzerland.
- An application to Swiss candy production suggests there is substantial excess heat available, which can be valorised through heat pump integration and used for process heating applications. Alternatively, this heat can be used for space heating.
- Another highly relevant technology is the steam-generating heat pump, especially for retrofits where it is too costly to change the industrial process to lower the temperature of the heating medium. The team is currently working with various companies to realise an industrial demonstration as quickly as possible.
- A key objective is also the development of new energy sources. For geothermal energy, the team identified areas with ideal underground conditions and combined these findings with the energy demand on the surface. In this way, so-called favourability maps were created that show where the use of geothermal energy is worthwhile. This is the case for large areas of the canton of Aargau. Further steps to investigate and utilise this potential are being planned in coordination with the canton. The aim is to realise a demonstration plant in the next few years.
- In the field of negative emission technologies the team could show the benefit of integrating heat pumps in an amine-based CO_2 separation process. Further work using energy system models highlighted the importance of new approaches such as membrane separation from smaller emitters or the storage of CO_2 in form of building material.
- A connection across all activities is the focus on the legal and socio-economic aspects of the energy transition. The team evaluates ways to reduce legal, social, and economic barriers for the development and implementation of clean heating and cooling solutions. On the legal side, challenges regarding thermal grids and the replacement of fossil heating systems are assessed.

Faits marquants

Les principaux faits marquants (résultats, défis, apprentissages, etc.) pendant la période de référence ont été les suivants :

- Il existe un potentiel important pour les réseaux de chauffage et de refroidissement urbains de 5e génération (5GDHC), d'autant plus que la demande de refroidissement dans le secteur du bâtiment approchera la demande de chauffage d'ici le milieu du siècle. Les éléments clés sont un stockage de chaleur par forage, qui est régénéré par la demande de refroidissement en été, et des pompes à chaleur, qui utilisent cette énergie stockée pour fournir le chauffage des locaux et l'eau chaude en hiver. Un projet de P&D avec la municipalité de Grandvaux (VD) est en cours.
- Combinée à des méthodes innovantes de distribution de la chaleur à basse température dans le bâtiment, la demande en électricité des pompes à chaleur peut être réduite. Pour l'ensemble de la Suisse, les innovations susmentionnées peuvent réduire la demande d'électricité en hiver de plusieurs TWh.
- Si les réseaux 5GDHC sont la solution de l'avenir, les réseaux à haute température existants peuvent également être optimisés en réduisant les températures, ce qui améliore considérablement leur efficacité en termes de production de chaleur et de pertes de distribution. Dans le cas d'un système de chauffage urbain de deuxième génération à Genève, une réduction du régime actuel de température d'alimentation et de retour de 110/70°C à 90/45°C permet d'augmenter le potentiel d'intégration des énergies renouvelables - en particulier la géothermie - de 75 % à 82 %.
- Dans le secteur industriel, l'objectif est de comprendre quelle quantité de chaleur est nécessaire à quelle température. Cela permet de réduire la consommation d'électricité des pompes à chaleur et de faciliter l'intégration des sources d'énergie renouvelables à basse température telles que l'énergie solaire et l'énergie géothermique. Une méthodologie a été mise au point pour créer des profils de demande d'énergie à l'échelle de l'entreprise pour diverses industries en Suisse.
- Une application à la production suisse de bonbons suggère qu'il existe un excédent de chaleur substantiel, qui peut être valorisé par l'intégration d'une pompe à chaleur et utilisé pour des applications de chauffage de processus. Cette chaleur peut également être utilisée pour le chauffage des locaux.
- Une autre technologie très pertinente est la pompe à chaleur génératrice de vapeur, en particulier pour les rénovations lorsqu'il est trop coûteux de modifier le processus industriel pour abaisser la température du fluide caloporteur. L'équipe travaille actuellement avec plusieurs entreprises pour réaliser une démonstration industrielle le plus rapidement possible.
- Le développement de nouvelles sources d'énergie est également un objectif clé. Pour l'énergie géothermique, l'équipe a identifié des zones présentant des conditions souterraines idéales et a combiné ces résultats avec la demande d'énergie en surface. Des cartes de favorabilité ont ainsi été créées, qui montrent où l'utilisation de l'énergie géothermique est intéressante. C'est le cas de vastes zones du canton d'Argovie. D'autres mesures visant à étudier et à exploiter ce potentiel sont en cours de planification en coordination avec le canton. L'objectif est de réaliser une installation de démonstration dans les prochaines années.
- Dans le domaine des technologies à émissions négatives, l'équipe a pu montrer les avantages de l'intégration de pompes à chaleur dans un processus de séparation du CO2 à base d'amine. D'autres travaux utilisant des modèles de systèmes énergétiques ont mis en évidence l'importance de nouvelles approches telles que la séparation par membrane des petits émetteurs ou le stockage du CO2 sous forme de matériaux de construction.
- L'accent mis sur les aspects juridiques et socio-économiques de la transition énergétique constitue un lien entre toutes les activités. L'équipe évalue les moyens de réduire les obstacles juridiques, sociaux et économiques au développement et à la mise en œuvre de solutions de chauffage et de refroidissement propres. Sur le plan juridique, les défis concernant les réseaux thermiques et le remplacement des systèmes de chauffage fossiles sont évalués.

Highlights

Die wichtigsten Highlights (Ergebnisse, Herausforderungen, Lehren usw.) während des Berichtszeitraums waren die folgenden:

- Es gibt ein beträchtliches Potenzial für Fernwärme- und Fernkältenetze der fünften Generation (5GDHC), zumal der Kühlbedarf im Gebäudesektor bis Mitte des Jahrhunderts dem Heizbedarf nahe kommen wird. Schlüsselelemente sind ein Erdwärmespeicher, der im Sommer durch den Kühlbedarf regeneriert wird, und Wärmepumpen, die diese gespeicherte Energie zur Bereitstellung von Raumheizung und Warmwasser im Winter nutzen. Ein P&D-Projekt mit der Gemeinde Grandvaux (VD) ist im Gange.
- In Kombination mit innovativen Niedertemperaturmethoden zur Verteilung der Wärme im Gebäude kann der Strombedarf von Wärmepumpen reduziert werden. Für die gesamte Schweiz können die genannten Innovationen den Strombedarf im Winter um mehrere TWh senken.
- Während 5GDHC-Netze die Lösung für die Zukunft sind, können auch die heute bestehenden Hochtemperaturnetze durch eine Senkung der Temperaturen optimiert werden, was ihre Effizienz in Bezug auf Wärmeerzeugung und Verteilungsverluste erheblich verbessert. Im Falle eines Fernwärmesystems der 2. Generation in Genf kann durch eine Senkung der derzeitigen Vorlauf-/Rücklauftemperatur von 110/70°C auf 90/45°C das Integrationspotenzial erneuerbarer Energien - insbesondere der Geothermie - von 75 % auf 82 % erhöht werden.
- Im Industriesektor geht es darum, zu verstehen, wie viel Wärme bei welcher Temperatur benötigt wird. Dies reduziert den Stromverbrauch von Wärmepumpen und erleichtert die Integration erneuerbarer Niedertemperatur-Energiequellen wie Solar- und Geothermie. Es wurde eine Methodik entwickelt, um unternehmensweite Energiebedarfsprofile für verschiedene Branchen in der Schweiz zu erstellen.
- Eine Anwendung auf die Schweizer Süßwarenproduktion zeigt, dass ein beträchtlicher Wärmeüberschuss vorhanden ist, der durch die Integration von Wärmepumpen aufgewertet und für Prozesswärmeanwendungen genutzt werden kann. Alternativ kann diese Wärme auch für die Raumheizung genutzt werden.
- Eine weitere sehr relevante Technologie ist die dampfbetriebene Wärmepumpe, insbesondere für Nachrüstungen, bei denen es zu kostspielig ist, den industriellen Prozess zu ändern, um die Temperatur des Heizmediums zu senken. Das Team arbeitet derzeit mit verschiedenen Unternehmen zusammen, um so schnell wie möglich eine industrielle Demonstration zu realisieren.
- Ein wichtiges Ziel ist auch die Erschließung neuer Energiequellen. Für die Geothermie hat das Team Gebiete mit idealen Untergrundbedingungen identifiziert und diese Erkenntnisse mit dem Energiebedarf an der Oberfläche kombiniert. Auf diese Weise entstanden so genannte Günstigkeitskarten, die zeigen, wo sich die Nutzung der Erdwärme lohnt. Dies ist für weite Teile des Kantons Aargau der Fall. In Abstimmung mit dem Kanton sind weitere Schritte zur Erkundung und Nutzung dieses Potenzials geplant. Ziel ist es, in den nächsten Jahren eine Demonstrationsanlage zu realisieren.
- Im Bereich der negativen Emissionstechnologien konnte das Team den Nutzen der Integration von Wärmepumpen in einen amin-basierten CO2-Abscheidungsprozess aufzeigen. Weitere Arbeiten mit Energiesystemmodellen zeigten die Bedeutung neuer Ansätze wie die Membranabscheidung aus kleineren Emittenten oder die Speicherung von CO2 in Form von Baumaterial.
- Eine Verbindung über alle Aktivitäten hinweg ist der Fokus auf die rechtlichen und sozioökonomischen Aspekte der Energiewende. Das Team prüft Möglichkeiten zum Abbau rechtlicher, sozialer und wirtschaftlicher Hindernisse für die Entwicklung und Umsetzung sauberer Wärme- und Kühllösungen. Auf der rechtlichen Seite werden die Herausforderungen in Bezug auf Wärmenetze und den Ersatz fossiler Heizsysteme bewertet.

Punti salienti

I principali punti salienti (risultati, sfide, lezioni apprese, ecc.) durante il periodo di riferimento sono stati:

- Esiste un potenziale significativo per le reti di teleriscaldamento e teleraffreddamento di quinta generazione (5GDHC), soprattutto perché la domanda di raffreddamento nel settore edilizio si avvicinerà a quella di riscaldamento entro la metà del secolo. Gli elementi chiave sono l'accumulo di calore in pozzo, che viene rigenerato dalla domanda di raffreddamento in estate, e le pompe di calore, che utilizzano l'energia accumulata per fornire riscaldamento e acqua calda in inverno. È in corso un progetto P&D con il comune di Grandvaux (VD).
- In combinazione con metodi innovativi a bassa temperatura per distribuire il calore nell'edificio, è possibile ridurre la domanda di elettricità delle pompe di calore. Per la Svizzera nel suo complesso, le innovazioni citate possono ridurre il fabbisogno invernale di elettricità di diversi TWh.
- Se le reti 5GDHC sono la soluzione per il futuro, anche le attuali reti ad alta temperatura possono essere ottimizzate riducendo le temperature, migliorando significativamente la loro efficienza in termini di generazione di calore e perdite di distribuzione. Nel caso di un sistema di teleriscaldamento di seconda generazione a Ginevra, la riduzione dell'attuale regime di temperatura di mandata/ritorno da 110/70°C a 90/45°C consente di aumentare il potenziale di integrazione delle energie rinnovabili - in particolare della geotermia - dal 75% all'82%.
- Nel settore industriale, l'obiettivo è capire quanto calore è richiesto a quale temperatura. In questo modo si riduce il consumo di elettricità delle pompe di calore e si facilita l'integrazione delle fonti di energia rinnovabile a bassa temperatura, come il solare e la geotermia. È stata sviluppata una metodologia per creare profili di fabbisogno energetico a livello aziendale per vari settori industriali in Svizzera.
- Un'applicazione alla produzione di caramelle in Svizzera suggerisce che esiste un notevole eccesso di calore disponibile, che può essere valorizzato attraverso l'integrazione delle pompe di calore e utilizzato per applicazioni di riscaldamento di processo. In alternativa, questo calore può essere utilizzato per il riscaldamento degli ambienti.
- Un'altra tecnologia molto importante è la pompa di calore per la generazione di vapore, soprattutto per gli interventi di retrofit in cui è troppo costoso modificare il processo industriale per abbassare la temperatura del mezzo di riscaldamento. Il team sta attualmente collaborando con diverse aziende per realizzare una dimostrazione industriale nel più breve tempo possibile.
- Un obiettivo chiave è anche lo sviluppo di nuove fonti energetiche. Per quanto riguarda l'energia geotermica, il team ha identificato le aree con condizioni sotterranee ideali e ha combinato queste scoperte con la domanda di energia in superficie. In questo modo, sono state create le cosiddette mappe di favore che mostrano dove l'uso dell'energia geotermica è conveniente. Questo è il caso di vaste aree del Canton Argovia. In collaborazione con il Cantone si stanno pianificando ulteriori iniziative per studiare e sfruttare questo potenziale. L'obiettivo è realizzare un impianto dimostrativo nei prossimi anni.
- Nel campo delle tecnologie a emissioni negative, il team ha potuto dimostrare i vantaggi dell'integrazione delle pompe di calore in un processo di separazione della CO2 a base di ammina. Un ulteriore lavoro, svolto utilizzando modelli di sistemi energetici, ha evidenziato l'importanza di nuovi approcci, come la separazione a membrana da emettitori più piccoli o lo stoccaggio della CO2 sotto forma di materiale da costruzione.
- Un collegamento tra tutte le attività è l'attenzione agli aspetti legali e socio-economici della transizione energetica. Il team valuta come ridurre le barriere legali, sociali ed economiche per lo sviluppo e l'implementazione di soluzioni pulite di riscaldamento e raffreddamento. Dal punto di vista legale, vengono valutate le sfide relative alle reti termiche e alla sostituzione dei sistemi di riscaldamento fossili.

1 Highlights of the reporting period

The DeCarbCH project addresses the challenge of decarbonising heating and cooling in Switzerland within the next three decades. The overall objective is to facilitate, speed up and de-risk the implementation of renewables for heating and cooling in the residential and in the industry sector.

District heating (and cooling) networks

An important subject of study in the past year was **5th generation district heating and cooling (5GDHC) networks**. New modelling results were obtained both on the detailed local and on the overall national energy system level. Using the new software TESSA[1], it could be shown that there is a significant and increasing potential for 5GDHC networks, especially once cooling demand is at least equal to half of the heating demand. Borehole thermal energy storage is very complementary to this technology by providing low temperature thermal storage suitable for seasonal storage and regeneration. Such a system reduces the temperature lift at which the heat pumps operate, thereby reducing the electricity demand in the colder months. Within a Pilot and Demonstration project with the commune of Grandvaux (VD) it could be shown by simulations how 5GDHC networks can be implemented in a historic village[2].

A complementary study focused on the energy performance and sizing criteria for **5GDHC networks**, examining how the **heat distribution temperature within buildings** impacts overall network efficiency. An energy simulation model, developed using Modelica, was applied to a Danish case study, exploring the effects of varying building heating system temperatures on network performance (similar studies will soon be done on Swiss cases). By demonstrating **significant electricity savings** through the adoption of **lower temperature heat distribution systems**, the study highlights the potential for integrating low-grade renewable heat sources (such as lake water or shallow geothermal) more effectively for the purposes of heating and cooling. These findings provide essential guidance for the strategic development and improvement of future thermal networks, contributing to the design of more sustainable and resilient urban heating and cooling systems. They underscore the importance of **prioritizing exergetic efficiency** – largely driven by the performance of (decentralized) heat pumps – in the design of next-generation thermal networks.

In parallel to the two aforementioned detailed case studies, the same subject was tackled with the SES-ETH **energy system model at national scale**. The value of innovations such as **5GDHC networks, borehole regeneration – equivalent to low-Δ-temperature thermal energy storage – and low temperature heat delivery systems** (e.g. convective systems) was assessed. The results indicate that all these innovations together can **save total system costs and several TWh of valuable and expensive winter electricity**, making this the most important means to address the so-called “winter electricity gap problem” (see Figure 1). All these studies point at one fundamental insight: heat pumps are not just another technology to provide heat. Instead their adoption requires a re-thinking of thermal networks and heat delivery systems in building, all pointing at low temperatures and minimal temperature difference that allow for (i) very high heat pump COPs (>10), (ii) free cooling in summer, and (iii) a more viable integration of new renewable heat sources such as solar or geothermal energy.

While 5GDHC networks are the solution for the future, also today’s existing high temperature networks can be optimized by **reducing temperatures**, significantly improving their efficiency in terms of heat generation and distribution losses. This also facilitates the integration of renewable heat sources such as solar and geothermal energy, as well as the use of low-temperature sources (e.g. surface water, air, waste heat) in combination with heat pumps. This is **particularly important for wood-fired district heating systems**, which face imminent challenges as the demand for wood is projected to peak in less than five years, threatening the stability of supply and escalating operating costs.

[1] https://planeto-energy.ch/solution/

[2] https://www.aramis.admin.ch/Texte/?ProjectID=53156

In collaboration with the network operator of the biomass-fired district heating system in Losone (Energie Rinnovabili Losone) the team has further explored some of the measures that would allow the network temperature to be lowered. In particular, this study used numerical simulations to investigate the impact of improving the control of bypass valves at substation level on the network temperature.

Ongoing collaboration with grid operators and associations such as AEW, BAC and ADEV Energiegenossenschaft has confirmed the urgent need to replace wood with alternative renewable energy sources. The potential of wood biomass in Switzerland was recently quantified in a report for the Federal Office for the Environment (FOEN) as part of the Wood Action Plan[3]. Paraphrasing this report: As of 2021, approximately 6.8 million m3/year of wood energy potential was being utilized at 79%, leaving a remaining potential of 1.4 million m3/year. If all currently known larger, concrete projects are realized, utilization will rise to 94%. If, in addition to all currently known projects, all known "project ideas" today are also realized, consumption will exceed the available potential.

The work provided valuable guidance for the transition of high-temperature thermal networks and presents a comprehensive overview of actionable temperature reduction strategies. The cost-effectiveness of selected strategies underscores their potential for significant impact at minimal cost, helping stakeholders make informed decisions for sustainable grid transformation.

The team also studied temperature reduction strategies on two concrete test cases: (i) a **2nd generation (2G), urban district heating system** from the 1960s, delivering 359 GWh/a at 110°C/70°C (supply/return) and (ii) a **4th generation (4G) rural system** from 2007, delivering 5.8 GWh/a at 80°C/40°C. After a comparative overview of both case studies, their individual substations were ranked in terms of their influence on the return temperature. For the 2G system, monitoring of selected substations, combined with heat exchanger analysis, allows to further tackle the issue of high return temperatures, and to identify if the problem lies on the secondary side (building and/or distribution system) or on the district heating heat exchanger. For the 4G system, a specific monitoring campaign allowed to characterize advantages of cascade preparation of domestic hot water and space heating. In the case of the 2G district heating system, a modification of the current supply / return temperature regime (110/70°C) to a 3G temperature regime (90/45°C) would allow to **enhance the integration potential of renewable energies from 75% to 82%**. In terms of **integration of medium depth geothermal heat** (currently in prospective stage), and considering 5 doublets with 50 l/s flowrate, this technical improvement would result in economic gains of approximately 11 MCHF/a.

Industrial heat

The second major subject in DeCarbCH is industrial heat. It may seem at first quite different from the previously described work on heating and cooling networks, but it is essentially the same theme: (i) understand **how much heat is required at which temperature**, (ii) reduce this temperature to the level that is **really required by the end user**, (iii) allowing to **reduce heat pumps electricity consumption and integration of low-temperature renewable energy sources such as solar and geothermal**.

In order to achieve optimum integration of process heat electrification and renewable energy sources, it is important to have a comprehensive knowledge of process heating and cooling demands in the industrial processes. **The team developed a methodology to construct company-wide energy demand profiles** (using Grand Composite Curves, GCCs) for the different industries in Switzerland. To achieve this, methods to construct exemplar profiles and representative profiles were introduced.

The application of representative profiles was demonstrated to assess the potential of implementation of energy efficiency measures and decarbonization technologies (e.g., heat pumps, solar and geothermal) using the Swiss candy production as a case study. The heating and cooling profiles representative of typical company sizes were constructed based on the typical thermal requirements by process step. Figure 2 presents an example of representative profile for the annual candy production of 10 kt. The analysis of representative profile suggests there is **substantial excess heat available**, which can be

[3] https://www.aramis.admin.ch/Texte/?ProjectID=54080

valorised through heat pump integration and used for process heating applications. In addition, the representative profiles also facilitate the quantification of the **excess heat** remaining after exploiting the heat pump integration potential. This heat can be **used e.g. for space heating** (direct use or via district heating), which is a direct link to the work done on heating networks.

Heat pumps

Heat pumps are a common theme both for the work on district heating networks and industrial processes. Therefore, much effort is undertaken **on the knowledge dissemination for heat pump technology**. The team organized several talks, published articles, and hosted a webinar on steam generation heat pumps (in 2023 & 2024). These efforts significantly increased interest in this technology, both nationally and internationally. Companies have contacted the team to seek expertise, develop high-temperature heat pump concepts, or validate their internally developed concepts.

Steam-generating heat pump is a game-changing technology for decarbonizing industries especially in retrofit cases where it is too costly to modify the industrial process in order to reduce the temperature of the heating medium. The technology itself is not revolutionary but its implementation is very slow due to many obstacles related to components, costs, reduced availability, risk due to the novelty, and others. Currently there is no steam-generating heat pump installed and running in a Swiss industry but the **team is aiming for an implementation project**.

Geothermal energy source

An activity that was ramped up in the past year is the assessment of **geothermal energy** as new source both for district heating networks and industrial processes. A team in WP1 identified (i) areas with ideal subsurface conditions for geothermal prospection, and (ii) areas where subsurface criteria (reservoir, temperature, etc.) match with the energy demand at the surface. This led to **favourability maps that show where geothermal energy is worth exploiting**. Figure 3 shows that this is broadly the case for the **canton of Aargau**. Further steps to study and exploit this potential are currently being planned.

Negative emissions

Another important subject in DeCarbCH is **negative emissions**. After identifying waste-to-energy plants as the most important element to deliver these, a new focus was put on the **optimizing the heat integration of the CO_2 separation process with a plant and a district heating network**. Results show that the integration of a **heat pump** that valorises the heat rejection from the CO_2 absorber and delivers heat to a district heating network is beneficial for the economy of the integrated system.

Energy system modelling

Across all activities, the **energy system modelling** with the SES-ETH tool provides an element of integration. On one hand, technical solutions such as 5GDHC networks are implemented in a simplified way into SES-ETH, allowing to judge the **value of such technologies for the overall energy system**. On the other hand, the energy system results provide a framing for the more technically oriented work packages WP1, WP3-5. One element is the limited availability of biomass resources, that motivates the effort to integrate heat pumps and renewable resources such as solar or geothermal. This work, that is part of WP1 and WP12, allows also to identify new opportunities that were not considered at the time of the project definition, for instance the opportunity to generate **negative emissions by using wood as construction material** – that is then not available anymore to the energy system.

Legal and socio-economic aspects of the energy transition

A second frame that connects all activities is research that focuses on the **legal and socio-economic aspects of the energy transition**. It evaluates ways to reduce legal, social, and economic barriers for the development and implementation of clean heating and cooling solutions. Drawing on different case studies a coherent mapping of the dynamics that shape the development of thermal grids was developed (see Figure 4). This way, the diverse issues encountered in the case studies can be placed in a single framework.

On the legal side, challenges regarding thermal grids and the replacement of fossil heating systems were assessed. One example is the question of whether and how district heating networks should be put out to public tender. Two findings can be highlighted[4]: (1) The Confederation, cantons and municipalities can stipulate that the transfer of public tasks and the awarding of licences are not subject to procurement law. However, concessions for the construction and operation of thermal networks must in principle be awarded by means of a call for tenders if the economic utilisation of a cantonal or communal monopoly is transferred to private parties. Ultimately, the procedural provisions must comply with the general requirements of a constitutional administrative procedure: The principles of objectivity, non-discrimination and transparency are the guiding principles for the organisation of the specific tendering procedure. (2) Although the requirements for the award of construction and service concessions are also lowered in the EU, the legal comparison shows that the requirements for the procedure for the award of concessions are more clearly regulated in German law, for example, than in Switzerland, insofar as these are not covered by public procurement. In Germany, the requirements for the award procedure are lowered somewhat, but the Concession Award Ordinance also requires that the award be made in accordance with effective competitive conditions in these cases.

A second example is the question of how international and national climate targets in the building sector's heat supply can be implemented quickly through legal means[5]. Here the findings are: (1) To clarify the obligations of property owners, cantonal and municipal measures need to be better coordinated. Where regulations conflict, cantonal energy law should take precedence. (2) Cantonal law should rely on financial incentives and cooperative approaches, in addition to bans, to accelerate the transition. Hardship regulations and exceptions should minimize the financial burden on property owners. (3) Even with stricter municipal measures, municipalities must consider cantonal requirements and hardship regulations. This is to ensure that the rights of property owners are upheld. (4) The planned closure of gas networks by the Zurich City Council could be seen as an infringement on the property guarantee and the entrepreneurial freedom of gas network operators (e.g., Energie 360 Grad AG). Previous successes in decarbonization have been achieved through cooperation with Energie 360 Grad AG. A cooperative approach that relies less on coercion could promote acceptance of the measures and avoid conflicts with fundamental rights.

[4] See **https://sui-generis.ch/article/view/sg.249**

[5] **https://www.dike.ch/camprubi-dekarbonisierung-des-heizens-im-gebaudesektor**

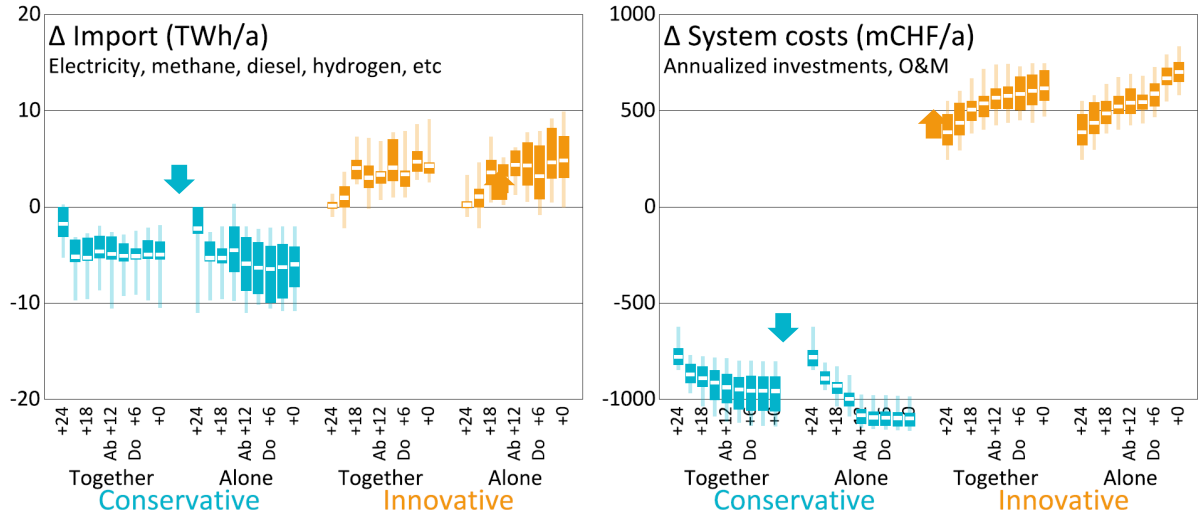

Figure 1: Difference of total imports and total system costs between baseline CROSS scenarios and variants; Adding heating system innovations to conservative scenarios **reduces imports and costs**; removing heating system innovations from innovative scenarios leads to **increased imports and costs**.

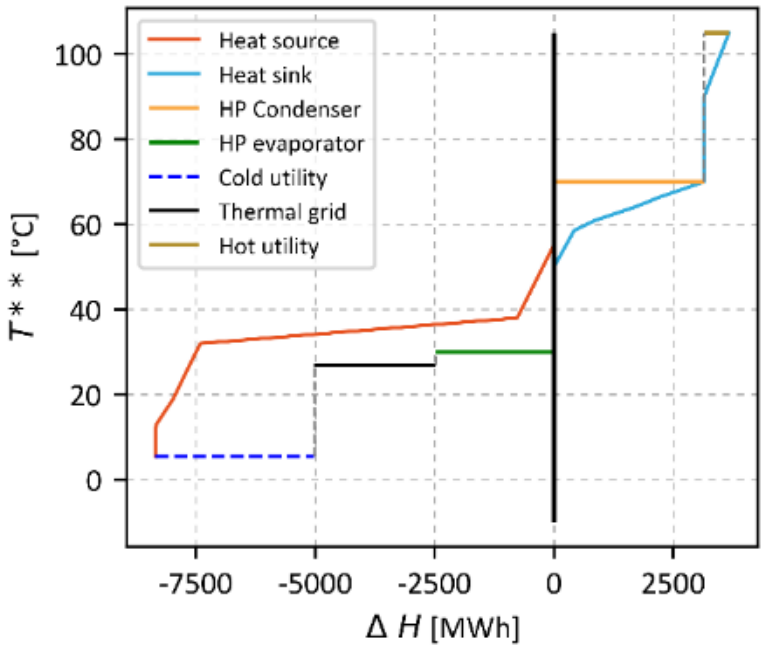

Figure 2: Representative profile for 10,000 tonne/year candy production

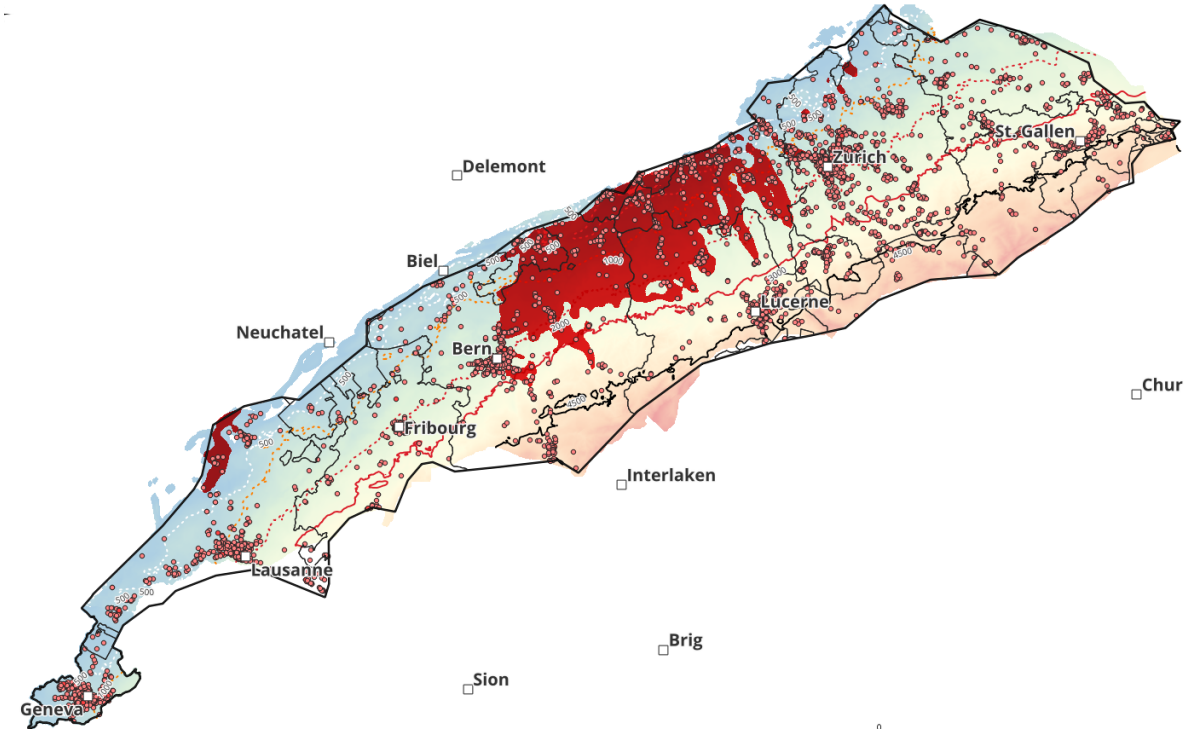

Figure 3: Area where subsurface temperatures reaches 70°C at 1500m deep, suitable for geothermal direct use coupled with location of high energy demands

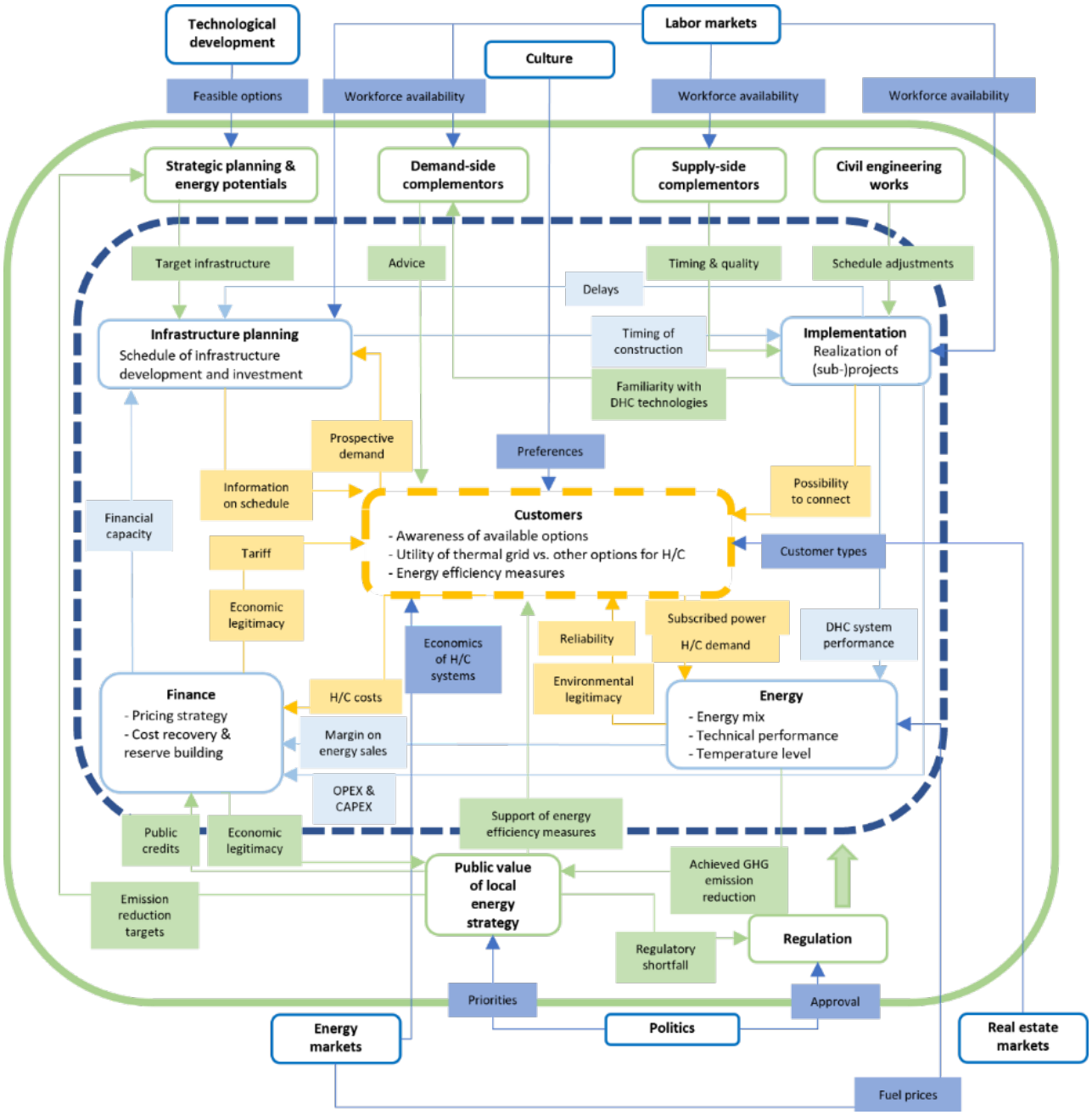

Figure 4: Subsystem diagram of the business dynamics of thermal grids.

2 Outputs of the reporting period

Peer-reviewed publications

Author(s), title, journal name, year	**doi**
Li, X., Yilmaz, S., Patel, M. K., & Chambers, J. (2023). Techno-economic analysis of fifth-generation district heating and cooling combined with seasonal borehole thermal energy storage. *Energy*, *285*, 129382.	**https://doi.org/10.1016/j.energy.2023.129382**
Li, X., Chambers, J., Yilmaz, S., & Patel, M. K. (2023, November). Sensitivity analysis of fifth generation district heating and cooling coupled with borehole thermal energy storage with respect to cooling adoption. In *Journal of Physics: Conference Series* (Vol. 2600, No. 6, p. 062008). IOP Publishing.	**https://iopscience.iop.org/article/10.1088/1742-6596/2600/6/062008**
Chambers, Jonathan, Stefano Cozza, and Martin Patel. "The GENEAP project: digitalising and automating planning of district heating and cooling." *Journal of Physics: Conference Series*. Vol. 2600. No. 8. IOP Publishing, 2023.	**https://iopscience.iop.org/article/10.1088/1742-6596/2600/8/082003**
Abegg/Seferovic, Ausschreibungsverfahren bei Gebietskonzessionen für thermische Netze am Beispiel der Stadt Zürich (Tendering procedure for site-based concession permits for district heating. Based on the example of the city of Zurich)	**https://sui-generis.ch/article/view/sg.249/4389**
Camprubi, Dekarbonisierung des Heizens im Gebäudesektor. Am Beispiel des Kantons und der Stadt Zürich (Decarbonisation of heating in buildings. Based on the example of the canton and the city of Zurich), Monography, Schriftenreihe zum Energierecht, Zürich 2024.	**https://doi.org/10.3256/978-3-03929-061-1**
Ch. Meyer, Die Regulierung des Heizkesselersatzes. Im Netz von Hard Law und Soft Law, Regeln und Prinzipien (The regulation of the boiler replacement. In the net of hard law and soft law, rules and principles), AJP 2023, p. 709 – 725.	**https://doi.org/10.21256/zhaw-29986**
Speich, M., Chambers, J. & Ulli-Beer, S.: Current and future development of thermal grids in Switzerland: an organizational perspective	**https://doi.org/10.3389/frsc.2024.1379554**
Baldini, Luca; Zambrano, Juan Mahecha, 2023. Thermochemical storage networks for integration of renewable energy sources through seasonal load shifting. Journal of Physics: Conference Series. CISBAT International Conference, Lausanne, Switzerland, 13-15 September 2023. IOP Publishing.	**https://doi.org/10.1088/1742-6596/2600/4/042001**
B.H.Y. Ong, N. Bhadbhade, D.G. Olsen, B. Wellig, Characterizing sector-wide thermal energy profiles for industrial sectors, Energy, 282, 129028, 2023	**https://doi.org/10.1016/j.energy.2023.129028**
J. Stampfli, B.H.Y. Ong, D.G. Olsen, B. Wellig, R. Hoffmann, Multi-objective evolutionary optimization for multi-period heat exchanger network retrofit, Energy, 281, 128175, 2023.	**https://doi.org/10.1016/j.energy.2023.128175**
N. Bhadbhade, M.K. Patel, Energy efficiency investment in Swiss industry: Analysis of target agreements, Energy Reports, 11, 624-636, 2023.	**https://doi.org/10.1016/j.egyr.2023.12.021**

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

Author(s), title, channel or type of publication, year
Sierro, F., Speich, M. & Ulli-Beer, S. (2024). Die Schweizer tiefe Geothermie mitten im Wandel. Geothermische Energie 107, 8-11.
Speich, M. & Ulli-Beer, S. (2024). Business implications of net-zero targets for district heating and cooling. International System Dynamics Conference 2024, Bergen, Norway.
Koirala, B., Bürglur, F., Humbert, G. & Yi-Chung Barton, C. (2024). Optimizing waste heat utilization from edge data centre [Poster presentation]. 3rd DeCarbCH Annual Networking Conference. 4.-5.3.2024. **https://www.sweet-decarb.ch/events/event/3rd-decarbch-annual-networking-conference**
F Bürgler, G Humbert, P Heer, B Koirala, Optimizing Waste Heat Utilization from Small-scale Data Centers in Multi-Energy Building Systems, International Conference on Applied Energy, 5-7 Dec 2023, Doha
Villasmil W., Mennel S. “Netze heute und morgen” in Themenheft 60: Thermische Netze. Faktor Verlag, ISBN: 978-3-905711-76-9, Zürich 2023.
Curti, V., Auer, M., Belliardi, M., Sotnikov, A., Innocenti, R., Villasmil, W. (2024). Guidelines on Temperature Reduction Strategies [Poster presentation]. 3rd DeCarbCH Annual Networking Conference. 4.-5.3.2024. **https://www.sweet-decarb.ch/events/event/3rd-decarbch-annual-networking-conference**
Benjamin H. Y. Ong, Andrin Duss, Jonas Grand, Raphael Agner, Beat Wellig. Design and Integration of a CO_2 Capture Plant using Piecewise Steady-State Simulation and Process Integration, Proceedings of the 26th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction, 8 – 11 October 2023, Thessaloniki, Greece.
Chambers, J.; Cozza, S.; Patel, M.: The GENEAP project: digitalising and automating planning of district heating and cooling. Paper presented at the CISBAT 2023 conference. Lausanne, 13-15 September 2023. Published in: Journal of Physics – Conference Series, 2023
Sasso, F.; Patel, M.K.: Thermal performance of residential and non-residential sectors: describing differences and understanding underlying reasons Paper presented at the CISBAT 2023 conference. Lausanne, 13-15 September 2023. Published in: Journal of Physics – Conference Series, 2023
Li, X.; Chambers, J.; Yilmaz, S.; Patel, M.K.: Sensitivity analysis of fifth generation district heating and cooling coupled with borehole thermal energy storage with respect to cooling adoption. Poster presented at the CISBAT 2023 conference. Lausanne, 13-15 September 2023. Published in: Journal of Physics – Conference Series, 2023
Raphael Agner, Andrin Duss, Jonas Grand, Beat Wellig. Piecewise-Steady-State Modelica Simulations for the Conceptual Design Phase of Industrial Processes. Proceedings of the 15th International Modelica Conference, October 9-11 2023, Aachen, Germany.

Invited talks (scientific or broad audience)

Presenter(s), title, name of the event and location, year
A. Abegg, Lunchtalk DeCarbCH, District Heating Supply. A Legal Classification, November 2023
M. Camprubi, Wärmeversorgung und Strom. Eine rechtliche Einordnung, Energierechtstagung Wärmeversorgung und Strom, Verbindung von Wärme und Strom als Baustein der Dekarbonisierung? Tagungsreihe zum Energie- und Nachhaltigkeitsrecht, School of Management and Law, ZHAW, Zürich, 5. September 2023.
Villasmil W, *Transformationspfade für erneuerbare Energie: Thermische Netze und Digitalisierung im Fokus*. Drittes Hybridsymposium ”Hygiene und Energie”, 26.10.2023.
Villasmil W, *The Role of Renewables and Thermal Grids in the Decarbonization of Energy Districts*. District Energy Latam Conference 2023, Cartagena (Colombia), 27-29.09.2023.
Villasmil W, *Thermische Energiespeicher – Chancen für die Dekarbonisierung des Wärmesektors*. Tagung zum Energie- und Nachhaltigkeitsrecht, Winterthur, 05.09.2023.

Villasmil W, *Thermische Energiespeicher – Chancen für die Flexibilisierung und Dekarbonisierung von Thermischen Netzen*. Workshop WWZ, Zug, 19.10.2023.
Saisonale Wärmespeicher – attraktiv, jedoch vernachlässigt. Energie-Apéro Chur, 31.5.2023. (invited talk)
Auer, M., Technologies, design, and operation of thermal grids for future energy planning, Forschungsplenum 2023 – Hochschule Luzern T&A, 24th January 2023, Luzern, Switzerland
Bohren A, Grosse Solarkollektoren: Welcher Kollektor für welches Wärmenetz?, Solarenergie und Wärmepumpen - Thermische Netze, Rapperswil 2.11. 2023
Benjamin H. Y. Ong, Andrin Duss, Jonas Grand, Raphael Agner, Beat Wellig. Design and Integration of a CO_2 Capture Plant using Piecewise Steady-State Simulation and Process Integration, Proceedings of the 26th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction, 8 – 11 October 2023, Thessaloniki, Greece
Patel, M.K.; Chambers, J.; Li, X.; Wellig, B.; Guidati, G.; Bertsch, S.; Arpagaus, C.; Bless, F.: Contribution to IEA Experts' Group on R&D Priority-setting and Evaluation (EGRD) on Climate Neutral Heating and Cooling: R&D needs & perspectives for international collaboration. On-line event, 20 April 2023
Patel, M.K.: Decarbonisation of Heating and Cooling in Industry. Insights from the SWEET-DeCarbCH project. Inputs to UNECE's Group of Experts on Energy Efficiency (GEEE). UNECE, Geneva, 6 October 2023
Patel, M.K.: Analysis of innovative solutions for thermal grids (original title in French: Analyse de solutions innovantes pour les réseaux thermiques). Fernwärmeforum 2024 (Forum du chauffage à distance 2024). Conference organized by Thermische Netze Schweiz, Bern, 25 January 2024
Patel, M.K.; Villasmil, W.: Dekarbonisierung der Wärme- und Kälteversorgung mittels thermischer Netze. 20. IGE-Seminar. Institute for Building technology and Energy (Institut für Gebäudetechnik und Energie, IGE), HSLU, Horw, 13. März 2024

Completed PhD theses

Author, title, year
Stefano Cozza, *Data-driven Assessment of the Energy Performance Gap in Residential Buildings in Switzerland and Implications for Retrofit Strategies*, UNIGE, 2022
Jan A. Stampfli, *Retrofit for multi-period processes for practical heat exchanger network design*, HSLU, 2023
Navdeep Bhadbhade, *Technology and Investment Options for Total Final Energy Reduction and CO_2 Abatement in the Swiss Industry*, UNIGE, 2023
Xiang Li, *Shallow geothermal energy in district heating and cooling: a potential solution for decarbonising heating and cooling*, UNIGE, 2024

Completed master theses

Author, title, year
Roxanne van den Berghe, Optimal sizing and operation of hydrogen generation site with waste heat recovery, 2023
Josien de Koning, Long and short term flexible control of power-to-hydrogen system with terminal cost function and flexibility envelope, 2023
Florian Bürgler, Integration of small-scale data centers in multi-energy building systems, 2023
Bernandino, Economic and environmental assessment of heat prosumer communities, 2024
Djordje Kruklianin, Erdbeckenwärmespeicher im Kiesabbaugebiet, 2023
Michael Giger, Simulation, Integration and Evaluation of Carbon Capture, Liquefaction and P2X Processes, 2024

Licences

Subject, license holder, year, brief description
PinCH Software, HSLU, 2023, Leasing and Purchase models, Software to support application of Pinch Analysis in industry

Other outputs

Brief description
Energy Optimization with Pinch Analysis course in German as well as English in 2023. 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.
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 IFEC Ingenieure SA, Weisskopf Partner GmbH, Lippuner EMT AG, Hofstetter Gastechnik AG, Evonik Industries AG (Germany), Altana AG (Germany/Texas, US) and BLS Energieplan GmbH.
Flat Plate Collectors - Factsheet 1: Integration of solar energy in district heating. **https://www.ost.ch/fileadmin/dateiliste/3_forschung_dienstleistung/institute/spf/forschung/empfehlungen/factsheets_solarwaerme_fuer_waermenetze/01_factsheet_fpc.pdf**
Evacuated Tube Solar Collectors - Factsheet 2: Integration of solar energy in district heating. **https://www.ost.ch/fileadmin/dateiliste/3_forschung_dienstleistung/institute/spf/forschung/empfehlungen/factsheets_solarwaerme_fuer_waermenetze/02_factsheet_vtc.pdf**
Parabolic Trough Collectors - Factsheet 3: Integration of solar energy in district heating. **https://www.ost.ch/fileadmin/dateiliste/3_forschung_dienstleistung/institute/spf/forschung/empfehlungen/factsheets_solarwaerme_fuer_waermenetze/03_factsheet_ptc.pdf**
Vacuum Flat Plate Solar Collector - Factsheet 4: Integration of solar energy in district heating. **https://www.ost.ch/fileadmin/dateiliste/3_forschung_dienstleistung/institute/spf/forschung/empfehlungen/factsheets_solarwaerme_fuer_waermenetze/04_factsheet_vfpc.pdf**
Photovoltaic Thermal Collector - Factsheet 5: Integration of solar energy in district heating. **https://www.ost.ch/fileadmin/dateiliste/3_forschung_dienstleistung/institute/spf/forschung/empfehlungen/factsheets_solarwaerme_fuer_waermenetze/05_factsheet_pvtc.pdf**
Cost and Economics - Factsheet 6: Integration of solar energy in district heating. **https://www.ost.ch/fileadmin/dateiliste/3_forschung_dienstleistung/institute/spf/forschung/empfehlungen/factsheets_solarwaerme_fuer_waermenetze/06_factsheet_cost.pdf**
Grid integration of solar heat - Factsheet 7: Integration of solar energy in district heating grids. **https://www.ost.ch/fileadmin/dateiliste/3_forschung_dienstleistung/institute/spf/forschung/empfehlungen/factsheets_solarwaerme_fuer_waermenetze/07_factsheet_integration.pdf**