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Industrial Process
and Energy Systems
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Energyscope Valais

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1 Abreviations

Abbreviation	Meaning
AG	Aargau
AI	Appenzell i.R
AR	Appenzell a.R
BE	Bern
BL	Basel Landschaft
BS	Basel Stadt
CH	Switzerland
ES35	Energetic Strategy 2035 Valais
FR	Freiburg
GE	Genève
GL	Glarus
GR	Graubünden
GWP	Global Warming Potential
JU	Jura
LU	Luzern
NE	Neuchâtel
NW	Nidwalden
OW	Obwalden
SES	Swiss Energyscope
SES 2.0	Swiss Energyscope
SG	Sankt Gallen
SH	Schaffhausen
SO	Solothurn
SZ	Schwyz
TG	Thurgau
TI	Ticino
UR	Uri
VD	Vaud
VS	Valais
VSES	Valais Energyscope
VSES 2.0	regionalized Valais Energyscope
ZG	Zug
ZH	Zürich

2 ABSTRACT

This document is the report of my second semester project at IPESE. It's objectives were to validate the energetic strategy 2035 of the "Canton du Valais" [1]. The lecturer will see how the Swiss-Energyscope model has been adapted to the canton of Valais to compare the scenario given by canton of Valais. By modelling the energetic model for the canton of Valais and simulating the outcome 2050, the role of Valais as part of Switzerland had to be considerd. The Swiss Energyscope (SES by Stefano Moret [2]) regionalized by cantons has been created. The exchange of ressources (Waste, Wood, Gas and Electricity) has been visualized using a chord diagramm.
We were able to show the differences when optimizing on a more global aspect. In fact, the electricity production in Valais for 2050 7 times higher when optimizing Valais as a part of Switzerland comapred to the optimization on Valais only. This higher electricity generation has a 50% higher total cost.
We were able to validate the energetic strategy, due to same ressource use and similar cost (8% difference).

3 ABOUT R MARKDOWN

This semesterproject has furthermore the aim, to use R Markdown to generate the report and including automatically the results. This allows to change single parameters and figures, tables and numbers adapt automatically.
As the output is either in `html` or `pdf`, the templates are not on their final version and some issues have to be overcome. The main issue is for the PDF generation with the referencing of the figures and sources. The creation of automatic static screenshots of html widgets as the chord diagramms does not support the creation of captions. Furthermore it is not possible at the actual state to add captions for graphs as for tables.
This report has therefore been created with the best compromises in form and content to be presented, which leads to several troublesome small issues that are present in the report.

4 Introduction

The 2050 energy strategy, accepted by the Swiss population with the revised Energy Act in 2017, has as a means of reducing energy consumption by increasing energy efficiency and by increasing renewable energy.
The Industrial Processes and Energy Systems Engineering (IPESE) laboratory under the direction of Professor Maréchal at the EPFL Valais aims to work on processes and systems energy in order to use them efficiently and to reuse and convert energy in an efficient way and to integrate renewable energies into complex systems.
IPESE has created in 2015 a calculating tool “Energyscope”, in order to visualize the actual energetic situation and to determine the impact of future scenarios.
In the first part, Energyscope will be adapted to the canton of Valais to compare it with the “energetic strategy Valais”, elaborated by the governement of Valais (État du Valais).
The “Service de l’énergie et des forces hydrauliques” of the canton of Valais has created an energetic strategy 2035 (ES35) in 2018 [1]. It aims the energetic independence until 2060, regarding the total energy demand in the canton. It’s main aspects are, the reduction of energy consumption by modifying the behaviour and improving the energy efficiency of buildings, buildings, buildings and technical and vehicle installations. Furthermore it requests that the residual energy needs are met by renewable energy (electricity and heat) produced locally and by unavoidable heat waste and that the renewable energy production infrastructure, transmission and distribution networks distribution, as well as the energy storage units are mainly in Valaisan hands.
The aim of the project is to validate the energetic strategy of the canton of Valais by modelling Valais with its Districts. Furthermore it aims to model the impact on the solution, when optmizing on a bigger scope, being Valais as part of Switzerland.

5 MODELLING

5.1 MODEL INTRODUCTION

The Swiss Energyscope model is used to determine the impact of 6 indicators on the different energy scenarios (final energy consumption by application, power supply technology, mix of renewable energies, CO2 emissions, environmental impacts and annualised costs of the system). In addition, the calculator allows to check customer-specific scenarios and to develop new scenarios.
These are characterized by various parameters that are divided into 3 categories and define the scenario as follows:

- the end use
- the supply
- the energy price level

These parameters are defined in such a way that they do not exceed the potential of the region and the solutions remain feasible.
The SES has been modified by Gael Germano in his Master Thesis in order to generate a regionalized model [3]. Ressources ad demands have been splitted to regionalized variables and the transport between the different regions has been added. The regionalized model was used to generate the Energyscope Model of Canton de Vaud, especially with the focus on the district Gros-de-Vaud.

5.2 MODIFICATIONS

5.2.1 CORRECTIONS (POTENTIAL AND DEMAND ESTIMATION)

The main problem with the regionalized Energyscope model by Germano is, that the potential of ressources has not been adapted to the different regions in the same way as Moret did it in the initial Energyscope. In order to include the potential without adding constraints, the parameter `ref_size` has been augmented by an additional dimension, being `REGION`. The reference size of the potential can now be added for each region. This has a special impact on the hydropower potential. Moret forced the model to use the hydropower potential by setting `fmin` and `fmax` of the hydropowerplants to the same value as their reference size.

5.2.2 EXCHANGE

In order to generate more realistic exchange scenarios, the exchange between the regions is following the shortest road distance, according Google Maps. As in the VDES by Germano, only the distance between the main locations of each region are connected.
In order to shorten calculation time and make the model more realistic, the exchange between non-adjacent regions has been forbidden. This has been implemented by inserting constraints, setting the exchange to zero:

$$\dot{m}_{res,t,r_i \neq r_j} = 0$$

where $\dot{m}$ is the quantity exchanged in the exchange-network res at time t between regions r_i and r_j which are not equal and are not sharing a common border.

5.2.3 GAS

In order to simulate the gas exchange between regions, a new layer has been added to the exchange network `RES_EXCH`. The mandatory parametrs of this new layer `NG` are exchange cost and losses. Following assumptions have been stated:

- Already existant Gas Network.
- The pipelines are following the course of the streets.

Table 1: Gas exchange network cost (Sogaval 2015)

	Value
Tranport Cost [MCHF]	49.44
Network length [km]	5521.00
Shipped NG 2015 [GWh]	882.20
specific shipping cost NG [CHF/km/GWh]	10.15

The already gas network implies, that no investment cost has to be paid when wanting to exchange between the regions. A already existant gas network connects the main parts of Switzerland, but not especially the main locations of the regions. In order to keep the same distances and paths between the regions for the exchange network, this hypothesis seems legit. In case of constructing new exchange infrastructure, the pipelines, electric grid and other possible networks will follow already existent infrastructures as roads. in fact, most of the roads follow the least expensive way to connect two nodes. The idea to follow this naturally dictated topography is the motivation behind this assumption.

The cost of transport has been estimated using data from SOGAVAL annual report 2015 [4]. The values used to calculate the specific shipping cost of Natural Gas are reported in the table 1.

$$c_{Gas}^{ship} = \frac{c_{Gas}^{trans}}{d_{Gas}^{Network} \cdot E_{Gas}^{2015}}$$

By combining the Trasnport cost c_{Gas}^{trans}, length of the gas distribution network of Sogaval $d_{Gas}^{Network}$ and the quantity of Energy transported in 2015 E_{Gas}^{2015}, the specific ship cost of Natural gas amounts to $c_{Gas}^{ship} = 10.15$ $[\frac{\mathrm{CHF}}{\mathrm{km \cdot GWh}}]$.
This specific cost has been applied to the distance between each region to determine the effective shipping cost.

5.2.4 MILP / LP

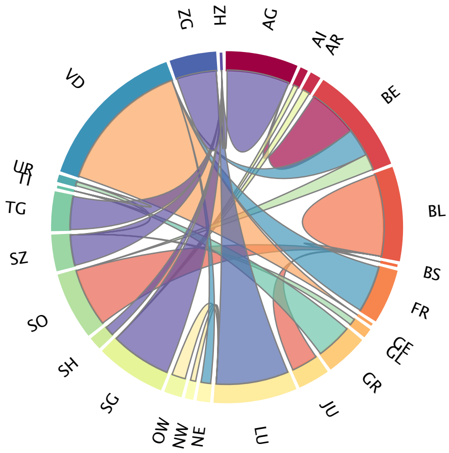
As the complexity of the problem increased exponentially with added regions (Valais: 13 regions, Switzerland: 26 cantons), the solver needed more time to compute an optimal solution. In fact„ the solvers Baron and Gurobi timed out, which lead to the decision to use the non-linear solver Conopt. In order to reduce the calculation time, the integer variable has been deleted. The MILP model is therefore reduced to LP, which reduces its complexity.
The variable `Number_of_Units` ($N_{i,r}$) guaranteed an integer number of installed units in the specific region. It is defined as the ratio beween the variable $F_{i,r}^{Mult}$ defining the the installed size according to the values of the layers of the in- and out table, while the parameter $size_{i,r}^{ref}$ is the reference size specific to each technology i.

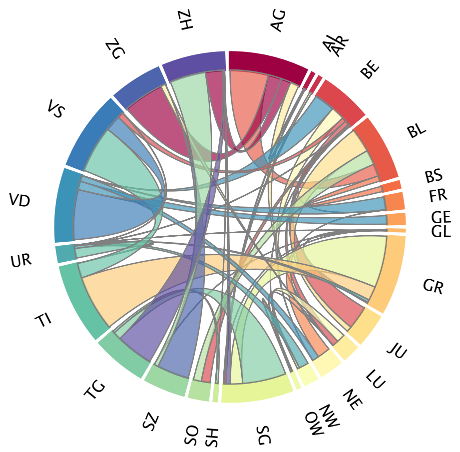
$$N_{i,r} = \frac{F_{i,r}^{Mult}}{size_{i,r}^{ref}}$$

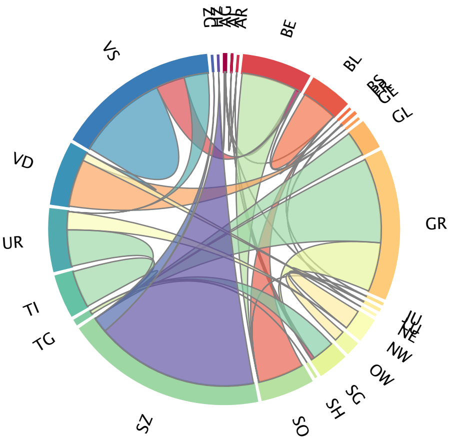
This simplification has no large impact, as a first approach when considering only trends. A different approach reducing the calculation time, is the separation of the electricity exchange into 3 voltage classes: High Voltage, medium Voltage and Low Voltage. By splitting these Voltages, only high voltage is exchange between regions and therefore less possibilities in exchange are created. This has not been implemented yet, but is recommended to do as next step.

5.2.5 Visualization

As the exchange between the regions has been modelled, an apropriate visualization diagram has been created. The selected method is the chord diagram. A first idea has been realized depicting the regions on the outer ring and depicting the exchanged flows between the regions, where the colour corresponds to the receiving canton. The size of the ring correpsonds to the produced quantity to leave in the different other regions by the specific region. One specific flow correpsonding to the exchange network (gas, waste, wood and electricity) can be visualized at once. In the three figures above, the Wood, Gas and Electricity exchanges are represented for the Swiss Energyscope 2050 under the constraints described in the respective section later on.







In the three figures above, the Wood, Gas and Electricity exchanges are represented for the Swiss Energyscope 2050 under the constraints described in the respective section later on. By considering the last figure, one can observe the some cantons generate a lot of exported Electricity as the canton of Valais or the Canton of Schwyz for example. Indeed do these cantons pocess a big amount of hydroelectric power and have a low population density per surface: Schwyz has a population density of 166.72 person per square kilometer, Valais of 62.59 and Zürich (being the biggest importer of electricity) of 824.52. Indeed, Schwyz and Valais are alpine cantons and have big surfaces without any settlement, in which hydropower plants are errected.

5.2.6 Adaptation number of regions

The data is specific to each region and has at the moment to be introduced manually into the `model.dat` file. The regionized Energyscope maodel has been adapted to 13 regions for Valais (number of districts) and to 26 for the Swiss Energycsope 2.0 (number of cantons).
This has been assessed by introducing the potential of each ressource into an Excel file and to pseudo-generate the code. This implementation will be explained in detail in the section “Data implementation”.

5.3 Data implementation

To avoid to genreate matrices manually with Excel, and to copy paste them in the `.dat` file, a first attempt to automatically generate these information using R Markdown.

5.3.1 Demands

In order to generate automatically the regionalized demand matrix, a Rmarkdown file has been created: `energyScopeDistricts.Rmd` and `energyScopeCantons.Rmd`. The demand determination are followed by the AMPL execution of the file including generation of the solution and Chord-diagram visualization. The following steps exlpain, how the data are combined to generate the input demand matrix for the regions. The demands are originated from the PROGNOS report [5], as in the previous Energyscope versions. The demand in sectors is defined according different scenarios (tables 3.35-3.52 in the prognos report). In the chunk in the appendix, all values with the different table sources from the PROGNOS report are introduced, converted into GWh and finally summarized in the end use, visible in section *Swiss Canton Energyscope (SES 2.0)*.

These tables are used in the model-execution file to adapt to the different regions and are afterwards automatically implemented into the SES AMPL model when changed.

In order to regionalize this data, the respective values have been scaled proportionally to different parameters: The only parameter being estimated for the year 2050 by the OFS (office fédéral de la statistique [6]), is the population by district. These values are available in “le Valais en Chiffre 2015”. Therefore the demands according to the sectors have been scaled proportionally to the population estimation for the regionalized model of Valais (VSES 2.0).
For Switzerland, the cantonal estimation of the heated surface, population, GDP, and so on are available by the OFS.
The best approximation for the estimation of demand potential is as following:

5.3.1.1 Housholds

The Energy demand of households $E_{r,t}^{households}[\mathrm{GWh}]$ at time $t[\mathrm{y}]$ for region (canton) r is proportional to the heated surface ratio $S_{r,t}^{heated}$ between the respective region and the swiss value $r = CH$:

$$E_{r,t}^{households} = E_{CH,t}^{households} \cdot \frac{S_{r,t}^{heated}}{S_{CH,t}^{heated}}$$

5.3.1.2 Services

The Energy demand of services $E_{r,t}^{Services}[\mathrm{GWh}]$ at time $t[\mathrm{y}]$ for region (canton) r is proportional to the population number $N_{r,t}^{pop}$ between the respective region and the swiss value $r = CH$:

$$E_{r,t}^{Services} = E_{CH,t}^{Services} \cdot \frac{N_{r,t}^{pop}}{N_{CH,t}^{pop}}$$

5.3.1.3 Industry

The Energy demand of the industry sector $E_{r,t}^{industry}[\mathrm{GWh}]$ at time $t[\mathrm{y}]$ for region (canton) r is proportional to the GDP (Gross domestic product) $GDP_{r,t}$ between the respective region and the swiss value $r = CH$:

$$E_{r,t}^{Industry} = E_{CH,t}^{Industry} \cdot \frac{GDP_{r,t}}{GDP_{CH,t}}$$

5.3.1.4 Transport

The Energy demand of the transport sector $E_{r,t}^{Transport,person}[\mathrm{M \cdot pers \cdot km}]$ or $E_{r,t}^{Transport,freight}[\mathrm{M \cdot t \cdot km}]$ at time $t[\mathrm{y}]$ for region (canton) r is proportional to the GDP (Gross domestic product) $GDP_{r,t}$ between the respective region and the swiss value $r = CH$:

$$E_{r,t}^{Transport,i} = E_{CH,t}^{Transport,i} \cdot \frac{GDP_{r,t}}{GDP_{CH,t}}$$

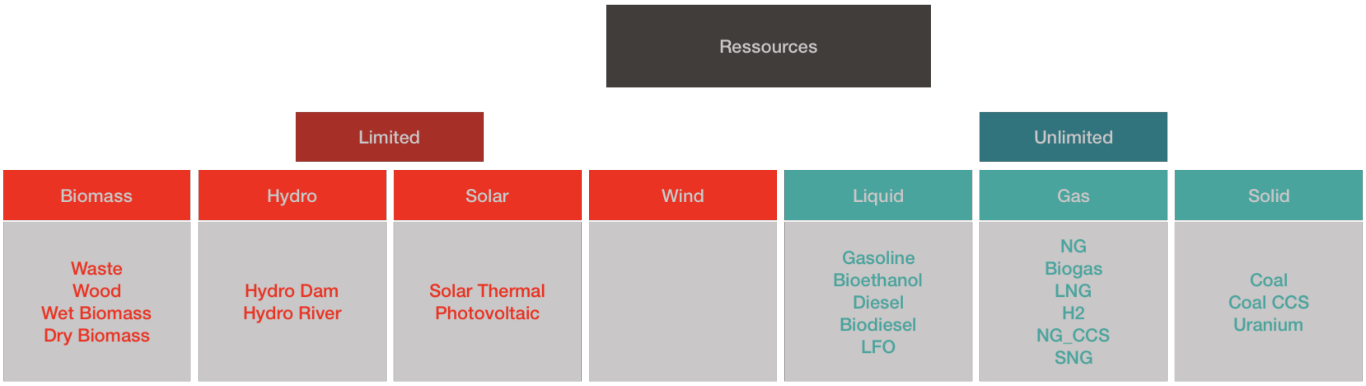


Figure 1: Categorization of the Ressources

5.3.2 Ressources

Unlimited ressources as gasoline, natural gas etc. are not restreined regionally and the upper limit of the original SES has been maintained. The limited ressources are presented herebelow and are summarized in the figure.

The necessary condition of limited potential of Switzerland E_i^{Pot} in $[\mathrm{GWh}]$ of ressource i is equal to the sum of the potential $E_{i,r}^{Pot}$ in each region r.

$$E_i^{Pot} = \sum_{r=1}^{n_{regions}} E_{i,r}^{Pot}$$

5.3.2.1 Hydropower

The hydropower plants are available from the “Office fédéral de l’Energie” (OFEN [7]). The report “Statistik der Wasserkraftanlaged der Schweiz” lists all hydropowerplants according to their type (run-off, accumulation, pumpage-storage) and the commune they’re located. From this list, the powerplants can be distributed into the according region and the available power defined into the AMPL `.dat` file.

5.3.2.2 Biomass

The Biomass data has been provided by Theodoros Damartzis [8] and summarizes the available biomass potential for each commune of Switzerland. The procedure is the same as for the hydropower potential, where the communal potetntial has been summed to the respective region.

5.3.2.3 Solar

Solar potential has been estimated by “Solardach.ch”. The potential for Valais has been defined in the previous semester project and has been impemented into the data file of the AMPL model.
For Switzerland, this step has not been executed, as the avialable shape file does have some geomertrical issues and does not les summarize via QGIS. In order to estimate the potential, the estimated total potential from PROGNOS report on Solar potential has been taken and made it proportional to the heated surface.
The implementation of the real potential has to be done when wanting to have a more precise model.

5.4 Validation

5.4.1 Objective function

After having introduced all relevant data into the model data file, the regionalized models have been compared to the basic models without regionalization under the same constraints. The important numbers to compare are the use of the ressources, as the objective function.

Table 2: Objective function value comparison basic vs regionalized model.

	VSES	SES
Basic Model [MCHF]	1346.60	23896.30
Regionalized Model [MCHF]	1391.50	25005.30
Relative Error [%]	3.33	4.64

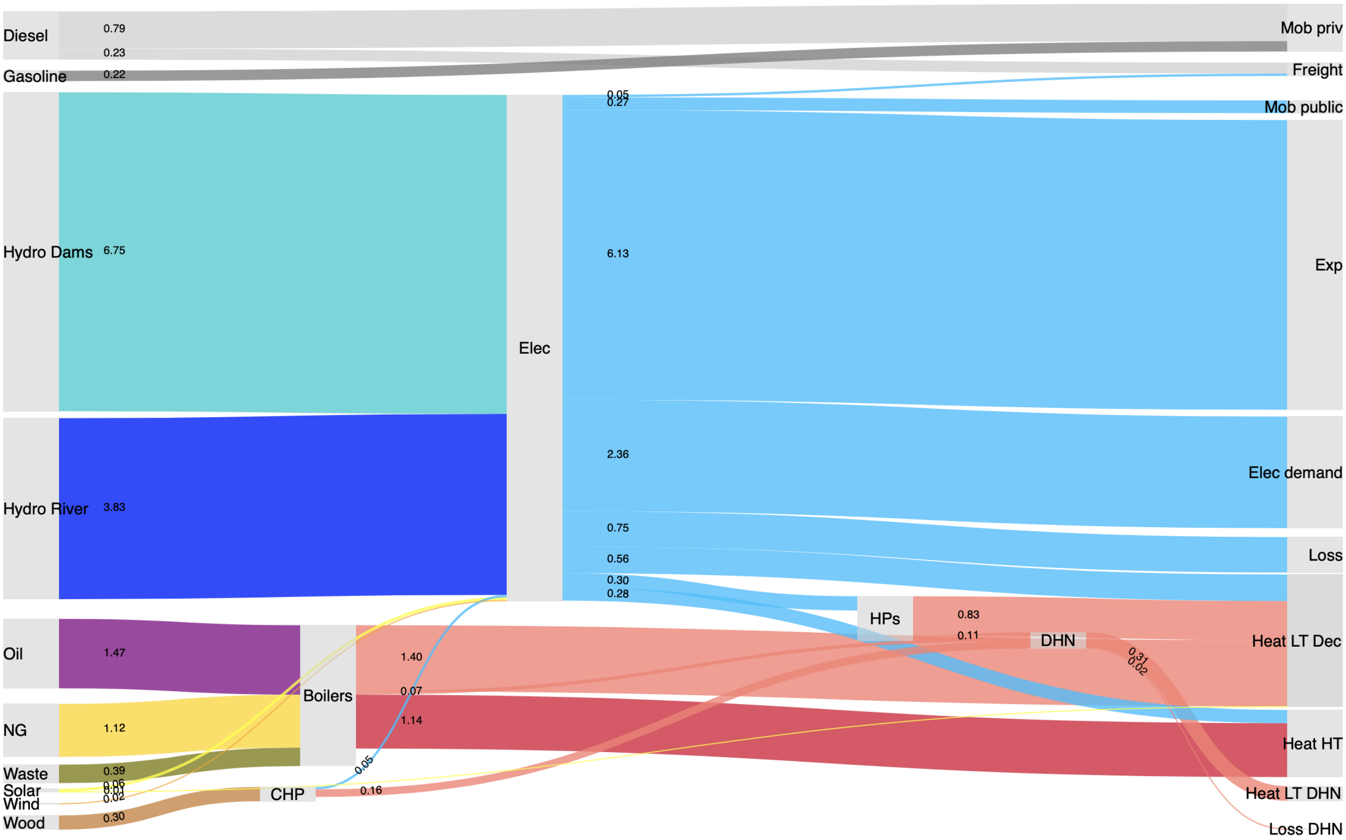
It can be observed in the table, that the objective function value for the cost minimization, is increasing slightly from the basic to the regionalized model (VSES: 3.33 % SES: 4.64). The increase of this value is due to the increasing cost, as it is not necessarly the best option in the different regions individually as for the main region in global.

5.4.2 Losses & Technologies

Furthermore, more losses are occurring, due to the transport of ressources. In the figures of this section, two Sankey diagrams are represented, showing the results to the constrained model according to the Energetic strategy 2035 of Valais. The first is the solution to the basic VSES (without regionalisation) and the second one with regionalisation. It is possible to observe small differences, mainly due to the reason described above. In fact, the electrical losses are increasing from the basic model solution (Electric losses 0.75 GWh) to the regionalized model (0.83 GWh).
In fact, due to the higher resolution in transport and grids, the electricity is distributed by a more precise grid, leading to more losses which need to be compensated.

5.4.3 Techologies

The higher resolution optimizes the global region by considering each smaller region. Little variations in the distribution and conversion technologies are observable. When taking the Low Temperature Decentralized Heat generated by Heat Pumps, it is observable that the basic model (0.83 GWh) generates less HP-heat than the HPs of the regionalized model (1.01 GWh). 2



5.4.4 Conclusion

The differences in the most important values, as the objective function, are varying below 5%. The main differences are due to the losses and the higher resolution of the model, resulting in a different technology use and therefore Energy distribution.

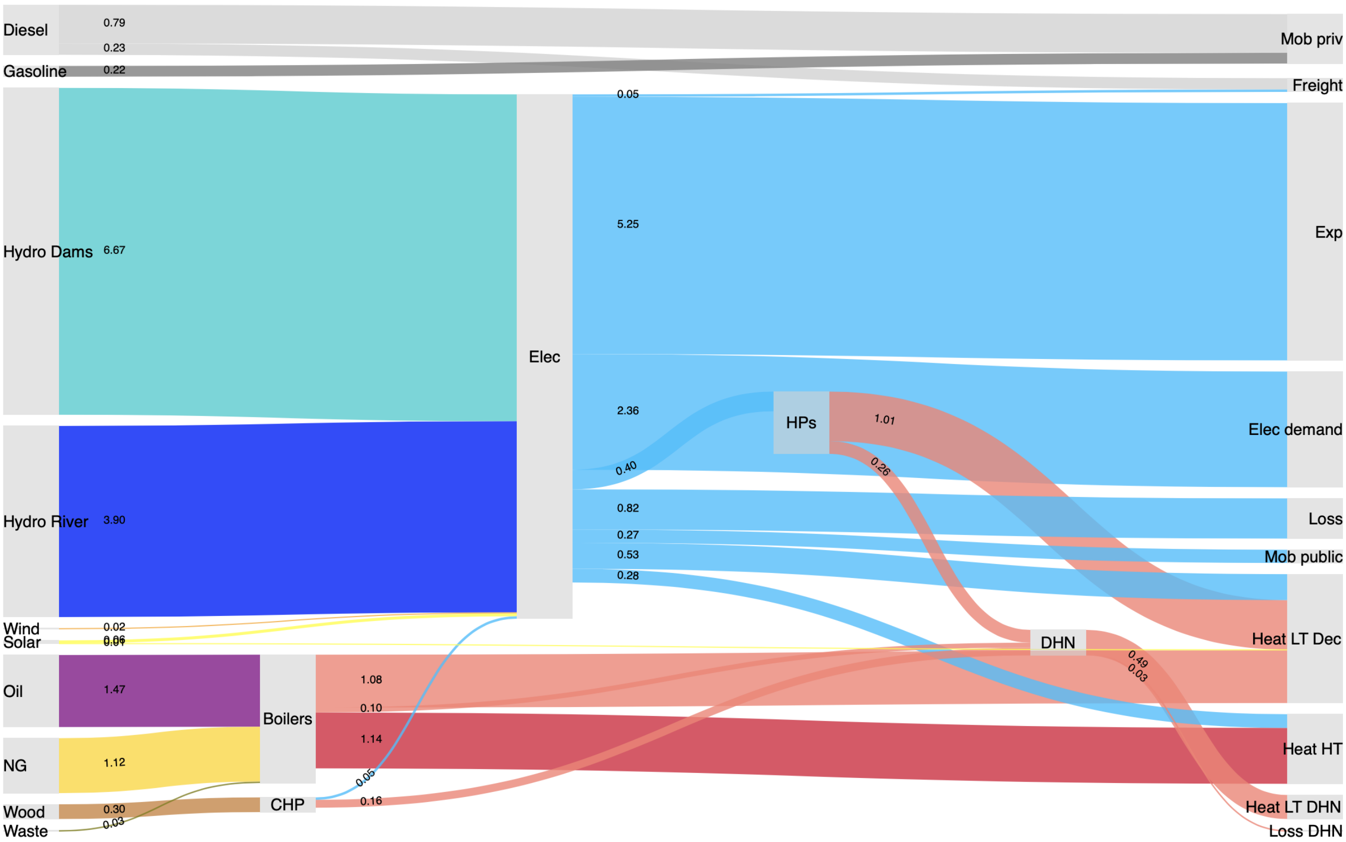


Figure 2: Sankey diagram VSES 2.0 2015, according the ES2035 (GWh)

6 Valais Energyscope (VSES 2.0)

After having assembled all available data regarding energetic matter in Valais, these datasets can now be applied to the Swiss-Energyscope model to create de Valais-Energyscope (VSES) model.
It retakes the same structure as the SES, but takes as reference year 2015 as the ES35 is calculating with this reference year.
Demand has been implemented, using a R Markdwon file, which launches the AMPL model and generates the visualization. The ressources data has still been implemented using Excel, having the advantage to directly being able to create matrices which are imported in the AMPL files. The implementation of the Ressources in the R Markdown model file will be done after the handing in of the report.

6.1 Regionalisation

The model has been created using as main region Switzerland with the cantons as regions. No additional constraints have been added to the model. The prupose of this model is to see the impact of Valais on the other cantons for an optimized & deffosilized case.

6.2 Reference year

The year 2015 has been chosen as reference year, as the ES35 is taking the same year as basis. This lets us compare the results from VSES to the data given in the report from Valais.

6.3 Specific data Canton of Valais

Consumption data has been used from the ES35 report. As it is confidential data, only used numbers can be documented and are summarized in the following tables: The Energy consumption has been summarized by the values in table *Energy consumption canton of Valais 2015 (ES35)* and is originated from the ES35.

Table 3: Energy consumption canton of Valais 2015 (ES35)

Agent énergétique	combustibles	carburants	Gaz naturel	Charbon	Electricité	Bois
Consommation [GWh/y]	1473	2493	1124	0	2358	157

The electricity production values have been summarized accordingly and are summarized in the table *Electricity production canton of Valais 2015 (ES35)*.

Table 4: Electricity production canton of Valais 2015 (ES35)

Source	Energie hydraulique	Photovoltaïque	éolienne	géothermie profonde
Production [GWh/y]	10577	60	18	0

In order to integrate these production and consumption values E_i^{ES35} (in $[\mathrm{GWh}]$) into the model, constraints have been created according:

$$\sum_{r}^{regions} \sum_{t}^{Periods} F_{i,r,t}^{Mult} \cdot t_i^{op} = E_i^{ES35}$$

where t_i^{op} is the operating time of the technology i.

6.4 Adaptation swiss data

The VSES needs several values which are not availabale for the Valais and therefore some adaptations had to be made. For the energy consumption, the demand on sectors have been made proportional to the same factors as for the regionalisation of the cantons: households to surface heated, service sector to the population, transport and industry to the GDP, as seen in section *modelling*. The calculated end use demand of Valais is therefore summarized in the table of this section. The code for the calculation is available in the appendix. The regionalization of the data from Valais has to be done using the only available data from the OFS, scoping into 2050 being the population:

$$E^s_{r,t} = E^s_{VS,t} \cdot \frac{N^{pop}_{r,t}}{N^{pop}_{VS,t}}$$

where s is the sector (households, industry, services, transport), t the year and $N^{pop}_{r,t}$ the population number of the district r.

Table 5: Energy demand end use VS 2015

	Households	Services	Industry	Transportation
Electricity [GWh]	396.60	448.61	392.82	0.00
Lighting [GWh]	61.10	166.28	50.42	0.00
Heat High Temperature [GWh]	0.00	0.17	2.32	0.00
Surface Heating [GWh]	148.99	626.04	145.90	0.00
Hotwater [GWh]	317.81	126.66	24.56	0.00
Mobility Passenger [M pers km]	0.00	0.00	0.00	3560.22
Mobility Freight [M t km]	0.00	0.00	0.00	809.83

6.5 Potential / Availability Ressources

The potential of the different ressources has been estimated in the previous semester project [9]. As explained in the section Data implementation, the the ressources can be splitted into two categories: limited ressources & unlimited ressources. The limited ressources are summarized in the table "Restreined ressources potential canton of Valais. Regionalized according districts.".

Table 6: Restreined ressources potential canton of Valais (2015). Regionalized according districts.

...1	Valais total	Brig	Conthey	Entremont	Goms	Hérens	Leuk	Martigny	Monthey	Raron	Saint-Maurice	Sierre	Sion	Visp
Waste [GWh]	386.82	39.90	26.72	17.26	6.63	17.99	18.14	42.28	43.48	16.21	11.46	56.92	46.02	43.81
Biomass dry [GWh]	307.16	16.15	33.59	20.09	19.48	3.36	14.73	26.31	6.10	17.39	8.25	83.81	11.39	46.51
Biomass wet [GWh]	401.65	7.01	21.46	16.00	16.70	13.14	11.58	27.34	7.49	67.35	6.11	196.84	1.37	9.25
Wood [GWh]	490.00	8.55	26.18	19.52	20.37	16.03	14.13	33.35	9.14	82.16	7.45	240.14	1.67	11.28
Solar thermic [GWh]	969.22	56.04	77.44	76.15	33.09	60.62	44.45	96.80	94.83	49.69	30.98	161.45	92.25	95.43
PV [GWh]	2167.37	135.63	202.08	132.06	70.89	91.74	110.63	271.20	209.33	130.53	61.93	312.00	239.25	200.10
Hydro Dam [GW]	3.42	0.01	0.00	0.47	0.01	0.06	0.02	2.04	0.01	0.33	0.16	0.13	0.00	0.18
Hydro River [GW]	0.91	0.09	0.05	0.07	0.20	0.01	0.01	0.02	0.03	0.22	0.01	0.05	0.03	0.12

6.6 SCENARIO 2050

6.6.1 DEMANDS

As for the demand 2015, the values have been scaled according the same criterias, using the available data from 2050. The code is available in the appendix. The scaling results in following values, for the strategy: “neue Energiepolitik” and taking as forecasted values from the OFS the mean strategy “Mittelweg”.

Table 7: Energy demand end use VS 2050

	Households	Services	Industry	Transportation
Electricity [GWh]	573.18	724.95	542.87	0.00
Lighting [GWh]	10.00	88.77	27.84	0.00
Heat High Temperature [GWh]	0.00	0.34	2.40	0.00
Surface Heating [GWh]	655.81	363.36	98.65	0.00
Hotwater [GWh]	293.24	167.12	51.44	0.00
Mobility Passenger [M pers km]	0.00	0.00	0.00	4366.84
Mobility Freight [M t km]	0.00	0.00	0.00	1291.69

6.6.2 RESSOURCES

In order to estimate the impact of the change in demand according to Prognos, the respectivbe values have been imported as explained above. The aim was to completely deffosilize the system and therefore all fossil ressources have been put to zero (all unlimited ressources which are imported).
The potential of the limited ressources has been calculated according to the growth given by the OFS, in the same manner as the demand definition.

Table 8: Restreined ressources potential canton of Valais 2050. Regionalized according districts.

...1	Valais total	Brig	Conthey	Entremont	Goms	Hérens	Leuk	Martigny	Monthey	Raron	Saint-Maurice	Sierre	Sion	Visp
Waste [GWh]	386.820	39.9000	26.7200	17.2600	6.63000	17.9900	18.14000	42.2800	43.4800	16.21000	11.46000	56.9200	46.0200	43.8100
Biomass dry [GWh]	307.160	16.1500	33.5900	20.0900	19.48000	3.3600	14.73000	26.3100	6.1000	17.39000	8.25000	83.8100	11.3900	46.5100
Biomass wet [GWh]	401.650	7.0100	21.4600	16.0000	16.70000	13.1400	11.58000	27.3400	7.4900	67.35000	6.11000	196.8400	1.3700	9.2500
Wood [GWh]	490.000	8.5500	26.1800	19.5200	20.37000	16.0300	14.13000	33.3500	9.1400	82.16000	7.45000	240.1400	1.6700	11.2800
Solar thermic [GWh]	1656.398	95.7724	132.3450	130.1404	56.55083	103.5996	75.96508	165.4313	162.0645	84.92024	52.94484	275.9182	157.6553	163.0899
PV [GWh]	3704.037	231.7918	345.3549	225.6906	121.15106	156.7837	189.06674	463.4810	357.7451	223.07585	105.83841	533.2082	408.8784	341.9710
Hydro Dam [GW]	3.420	0.0100	0.0000	0.4700	0.01000	0.0600	0.02000	2.0400	0.0100	0.33000	0.16000	0.1300	0.0000	0.1800
Hydro River [GW]	0.910	0.0900	0.0500	0.0700	0.20000	0.0100	0.01000	0.0200	0.0300	0.22000	0.01000	0.0500	0.0300	0.1200

Biomass category (according figure 1), has not been scaled as no reasonable approximation could have been stated.
Hydropower has been updated using data given by the OFEN, where the total of new Hydropower plants is estimated. This number is distributed proportionally according to the communes power already installed. The hydropower installed in Switzerland $E^{Pot}_{Hydro,2050}$ in $[\mathrm{GW}]$ is estimated to increase until 2050 by 12% (γ_{Hydro}).

$$E^{Pot}_{Hydro,2050} = (1 + \gamma_{Hydro}) \cdot E^{Pot}_{Hydro,2015}$$

Solar potential has been scaled according to the estimated heated surface 2050. This hypothesis can be underlined by the fact, that the estimation of the 2015 solra potential $E^{Pot}_{Solar,2015,r}$ for region r is based on the available roof surface. This parameter will vary in a similar way than the heated surface, as a roof gernerally shelters a heated surface.

$$E^{Pot}_{Solar,2050,r} = E^{Pot}_{Solar,2015,r} \cdot \frac{S^{heated}_{2050,r}}{S^{heated}_{2015,r}}$$

As only the cantonal data (VS in this case) are available, the proportionality of the ressources between districts $\delta_{2015,r}$ is remaining constant.

$$E^{Pot}_{Solar,2015,VS} = \sum_{r}^{districs} E^{Pot}_{Solar,2015,r} = \sum_{r}^{districs} \delta_{2015,r} \cdot E^{Pot}_{Solar,2015,VS}$$

Meaning that $\sum_{r}^{districs} \delta_{2015,r} = 1$ and the proportionality factor reamains constant $\delta_{2015,r} = \delta_{2050,r}$ which leads to

$$E^{Pot}_{Solar,2050,VS} = \sum_{r}^{districs} E^{Pot}_{Solar,2050,r} = \sum_{r}^{districs} \delta_{2015,r} \cdot E^{Pot}_{Solar,2050,VS}$$

7 Swiss Canton Energyscope (SES 2.0)

In order to see the influence of one canton to another, the regionalization has been applied to the Swiss Energyscope, by following the same methodology as applied for Valais. The different cantons as part of Switzerland can afterwards be compared to the optimization of canton only. Population data can be imported from data from Swiss Federal Bureau of Statistics (Bundesamt für Statistik) for each canton. This data is available as "Kantonsportäts 2015 []. Relevant data for parameter scaling are *population*, *living surface* and *Gross Domestic Product (GDP)*.
The basic data for the demands are taken from Prognos report as described in modelling section.

7.1 Reference year

2015 has been selected as reference year, as the data collected for Valais is available on national level and for all other cantons.

7.2 Specific data Switzerland

Specific data from Switzerland is available by several sources. The first data is from the OFS, providing the statistic data of previous years and scoping into the future. The raw data for each canton is represented in table *Cantonal Data Switzerland (OFS)*.

Table 9: Cantonal Data Switzerland (OFS)

Canton	Population 2015 [-]	Population 2050 mean [-]	Population 2050 high [-]	Population 2050 low [-]	Heated surface 2015 [m2]	Heated surface 2015 [m2]	GDP 2015 [MCHF]	GDP 2050 [MCHF]	Surface [m2]
CH	8139600	10703845.68	11728183.10	9719924.26	365.746676	526.3165779	601625.373	789322.9483	41284.98
ZH	1425500	1941115.77	2136408.74	1752693.66	63.149650	94.6429073	131934.684	179656.6084	1728.89
BE	1001300	1223320.96	1311699.71	1140189.74	44.627941	58.4624561	67791.731	82823.3756	5959.07
LU	390300	516146.32	555152.06	479424.69	17.485440	24.8708121	23771.331	31436.0369	1493.42
UR	35900	36421.65	39128.71	33976.03	1.573138	1.7146201	1749.512	1774.9334	1076.40
SZ	151400	197945.64	213784.12	182759.39	7.168790	10.1226781	8223.634	10751.8654	908.09
OW	36500	43611.28	47037.03	40779.48	1.664035	2.1444183	2120.015	2533.0568	490.55
NW	41900	45316.23	48794.59	42066.68	1.983127	2.3094479	2470.758	2672.2061	276.06
GL	39600	46721.10	50632.37	42653.08	1.920204	2.4551637	2319.407	2736.4959	685.40
ZG	118100	158748.74	176027.78	142108.46	5.488107	8.1800110	14778.825	19865.5361	238.72
FR	297600	467759.62	508939.02	428468.67	13.046784	22.3118868	14950.012	23498.0239	1670.84
SO	261400	333403.81	359022.61	308241.01	12.719724	17.4700403	15730.548	20063.5982	790.51
BS	189300	216517.33	245619.46	188725.02	7.944921	10.3086487	29681.254	33948.7897	37.07
BL	278700	323413.71	352267.38	295572.90	13.098900	16.5565668	19584.396	22726.4523	517.52
SH	78800	100929.69	110274.76	91563.44	3.923452	5.4905802	6101.483	7814.9837	298.50
AR	53700	60983.56	65369.31	57040.50	2.644188	3.2187850	2648.957	3008.2469	242.94
AI	15800	16321.68	17466.55	15303.02	0.712580	0.7877413	801.681	828.1506	172.50
SG	491700	613468.41	665933.43	563243.60	22.691955	30.7328277	32279.650	40273.6337	2025.45
GR	195000	219625.74	238563.23	201045.64	8.808150	10.7759013	11683.273	13158.7053	7105.15
AG	636400	882154.95	954789.69	812795.03	31.164508	46.7560513	41476.854	57493.7340	1403.79
TG	260300	367474.77	398296.81	337222.42	12.986367	19.8710281	14651.841	20684.5248	990.87
TI	346500	443230.59	491687.86	396176.51	16.202340	22.9913245	23080.725	29524.0495	2812.46
VD	749400	1069862.41	1197234.68	947268.69	31.901958	50.9662802	50329.203	71851.2442	3212.05
VS	327000	456081.69	498967.15	415116.20	14.113320	21.5354223	17614.470	24567.6985	5224.42
NE	176400	212269.21	234420.04	191243.36	7.682220	10.2089928	12546.556	15097.7750	803.06
GE	469400	626958.90	720797.68	536020.81	17.912304	27.5056394	49246.702	65776.8609	282.44
JU	71700	84041.89	89868.31	78226.24	3.132573	3.9263467	4057.871	4756.3622	838.81

7.3 Adaptation data Switzerland

7.3.1 Demands

The energetic demands for switzerland have been calculated previously. In order to regionalize the demands on the different cantons $E^s_{r,t}$, the procedure described in section modelling is applied. As all data for each region r (canton) is available from the OFS, no approximation as done in VSES 2.0 using only the population has to be made. The Swiss Energy demand

Table 10: Energy demand end use CH 2015

	Households	Services	Industry	Transportation
Electricity [GWh]	10277.78	11166.67	13416.67	0
Lighting [GWh]	1583.33	4138.89	1722.22	0
Heat High Temperature [GWh]	0.00	4.13	79.27	0
Surface Heating [GWh]	3861.11	15583.33	4983.33	0
Hotwater [GWh]	8236.11	3152.78	838.89	0
Mobility Passenger [M pers km]	0.00	0.00	0.00	121600
Mobility Freight [M t km]	0.00	0.00	0.00	27660

$E^s_{CH,t}$ can be scaled proportionally to the different sectors s as described in section 4.3.

$$E^s_{r,t} = E^s_{CH,t} \cdot \frac{\xi^s_{r,t}}{\xi^s_{CH,t}}$$

The relative parameters $\xi^s_{r,t}$ to the sectors are provided by the OFS data (table: *Cantonal Data Switzerland (OFS)*).

7.3.2 Ressources

The ressources are again splitted into two categories, on where the unlimited ressources did not have been applied the regionalization and the "infinite" value of Switzerland has been kept.
The restreined ressources are summarized in table *Preview of restreined ressources potential Switzerland (2015). Regionalized according cantons*. The complete table is available under Appendices.

Table 11: Preview of restreined ressources potential Switzerland (2015). Regionalized according cantons.

...1	CH	ZH	BE	LU	UR	SZ	OW	NW	GL	ZG	FR	SO
Waste [GWh]	11142.00	1951.31	1370.64	534.27	49.14	207.25	49.96	57.36	54.21	161.66	407.37	357.82
Biomass dry [GWh]	13951.97	1217.42	2804.37	783.19	78.20	337.69	206.60	89.22	112.37	83.42	597.91	769.13
Biomass wet [GWh]	8813.57	548.05	1632.81	998.04	33.13	239.96	102.04	71.61	39.26	185.26	746.99	184.68
Wood [GWh]	10291.00	1186.00	1875.00	614.00	98.00	246.00	115.00	99.00	118.00	134.00	345.00	283.00
Solar thermic [GWh]	8218.09	1301.82	920.00	360.46	32.43	147.78	34.30	40.88	39.58	113.14	268.96	262.22
PV [GWh]	54221.48	9348.37	6606.50	2588.46	232.88	1061.23	246.34	293.57	284.26	812.43	1931.38	1882.97
Wind [GWh]	9800.00	410.39	1414.53	354.50	255.51	215.56	116.44	65.53	162.70	56.67	396.61	187.65
Hydro Dam [GW]	8.07	0.00	0.67	0.00	0.16	0.05	0.10	0.01	0.39	0.00	0.13	0.00
Hydro River [GW]	3.98	0.10	0.31	0.01	0.29	0.06	0.04	0.03	0.11	0.01	0.07	0.10

7.4 Scenario 2050

7.4.1 Demands

As all statistic relevant data is available for the scaling of the swiss cantons, the end use demand can be calculated as described previously, with $t = 2050$.

$$E^s_{r,2050} = E^s_{CH,2050} \cdot \frac{\xi^s_{r,2050}}{\xi^s_{CH,2050}}$$

Ressources In order to adapt the ressources, the same method as used for the VSES 2.0 scenario 2050 is applied.
Biomass and wind category are remaining constant.
Hydro power is scaled according to the estimation of the OFEN, such that:

$$E^{Pot}_{Hydro,2050,r} = (1 + \gamma_{Hydro}) \cdot E^{Pot}_{Hydro,2015,r}$$

And finally the Solar category. Photovoltaic and solar thermal potential ${}^{Pot}_{Solar,2050,r}$ are scaled according to the heated surface development $S^{heated}_{t,r}$ from $t_1 = 2015$ to $t_2 = 2050$, specifically for each canton r.

$$E^{Pot}_{Solar,2050,r} = E^{Pot}_{Solar,2015,r} \cdot \frac{S^{heated}_{2050,r}}{S^{heated}_{2015,r}}$$

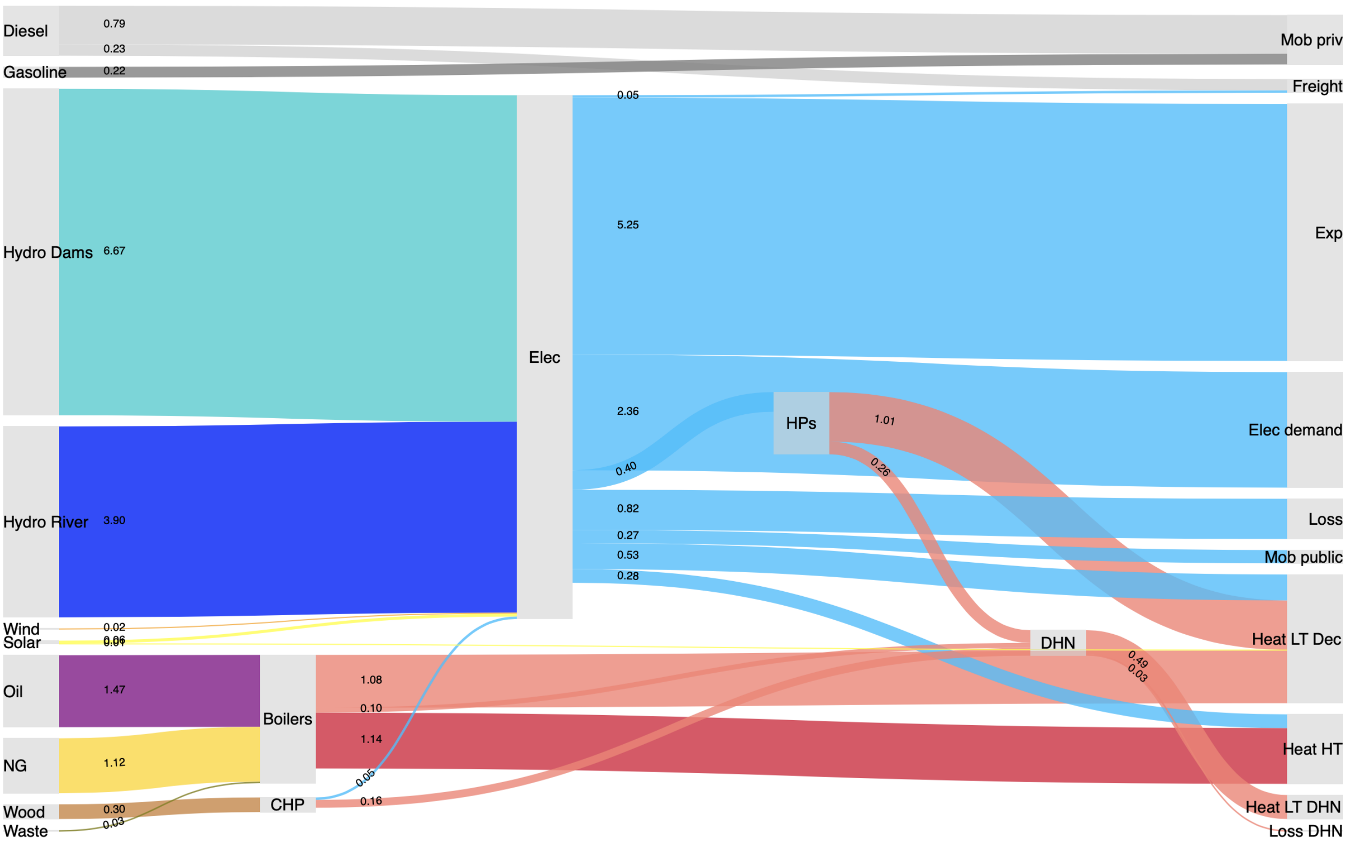


Figure 3: Sankey diagram VSES 2.0 2015, optimized on Total Cost (GWh)

8 Results

8.1 Canton of Valais 2015

8.1.1 Energy conversion Valais

In order to get a reference scenario to which the different optmized scenarios can be compared, the first characteristics to be introduced into the regionalized model is the base scenario from ES35 with the consumption and production constraints described previously.

By minimizing the Total Costs, this model leads to the solution shown in figure *Sankey diagram VSES 2.0 2015, optimized on Total Cost* depicting available energy production and end-use.

Table 12: Ressources used scenario VSES 2.0 ES35 2015

Ressources [GWh]	Diesel	Gasoline	Hydro Dams	Hydro River	Wind	Solar	Oil	NG	Wood	Waste	Wet Biomass	Dry Wood	El Export
VSES 2015	1.02	0.22	6.67	3.9	0.02	0.1	1.47	1.12	0.3	0.03	0	0	-5.25

The quantity of Hydropower used to generate electricity is striking, compared to the other ressources. In fact, 10.57 [GWh] of 14.85 [GWh] of the total ressources used, corresponding to 71.18 % is generated by hydropower plants.
Hydropower is used to to generate electricity which fulfills the electric needs and runs heat pumps to fulfill a part of the heat demand. The major part of the heat demand is guaranteed with fossile ressouirces, as Oil (1.47 [GWh]), Natural Gas (1.12 [GWh]) which are burned in boilers.
Renewable ressources (exept hydropower) have a minimal impact. In fact, Wind, Solar and Wood have a percentage of 2.83 % of the total ressources usage.

8.2 Canton of Valais 2050 VSES 2.0

In order to validate the ES35, a model has been generated having following criteria, as described in the strategy:

- Independent Valais: No import of ressources
- As renewable as possible: no fossil fuels to be imported

These objectives are resulting in the setting of fossil fuels and all other imports to zero. The model is run by minimizing the Total Cost and by applying the demand of 2050.

8.2.1 Energy conversion Valais

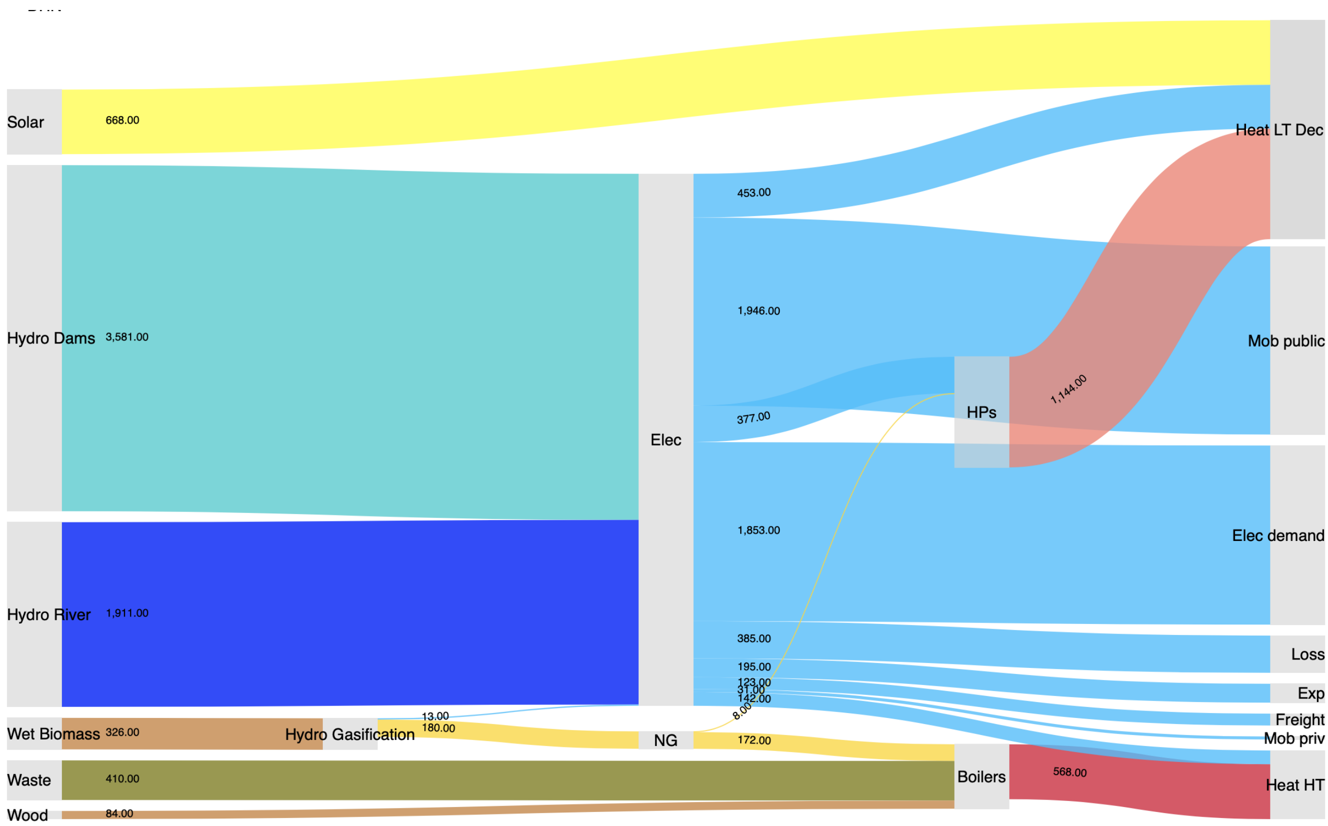


Table 13: Ressources used scenario VSES 2.0 ES35 2050

Ressources [GWh]	Diesel	Gasoline	Hydro Dams	Hydro River	Wind	Solar	Oil	NG	Wood	Waste	Wet Biomass	Dry Wood	El Export
VSES 2050	0	0	3.581	1.911	0	0.668	0	0	0.084	0.41	0.326	0	-0.195

It can be observed that Energy demand for mobility sectors is provided by electricity only, as all Fossil fuels (as Gasoline and Diesel) has been set to zero.
Heat Low Temperature is provided electric runned Heat Pumps, direct electric heating and solar thermic. In fact, the use of Electricity to generate Low temperature Heating can be explained by the trade-off between selling electricity or using it to heat instead of using other installations.
In fact, Valais has a surplus of Electricity generation due to the installed hydropower capacity. As in the 2015 case, most of the energy is supplied by hydropower, being 84.06.
It is striking that only solar heat is generated and noo photovoltaics are installed. This can again be explained by the abondand hydtropower which covers all electric needs and therefore no electricity genreating installation has to be installed in addition.

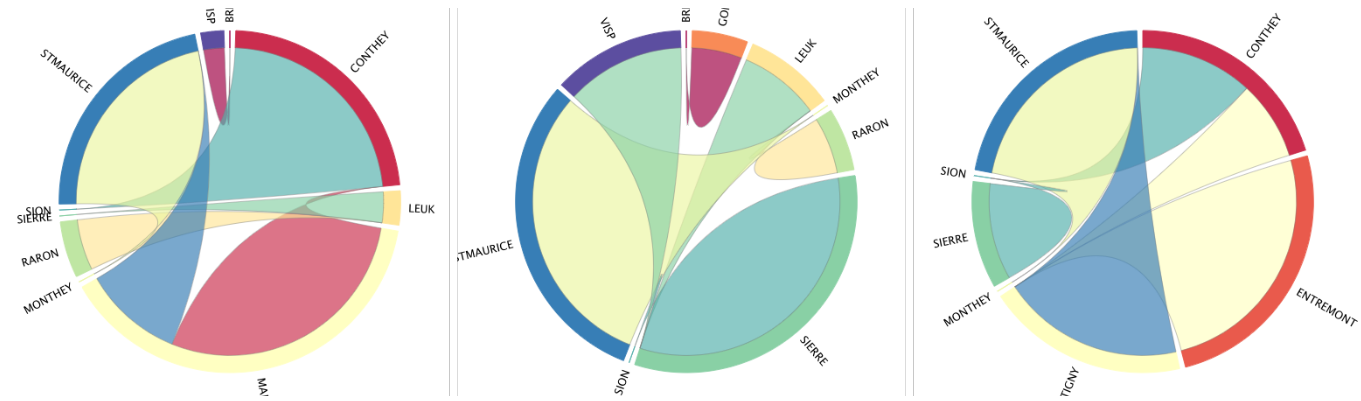


Figure 4: Chord diagram VSES 2.0 2050, optimized on Total Cost (MWh). Left Electricity, Middle Waste, Right Wood

8.2.2 Regionalization

The regionalized model allows to generate the energy conersion of each district. The exchange of ressources is depicted in the chord diagrams. The auto-consumption is not represented. It is striking to see that some districts are exporting a lot of ressources.
Electricity exchange for example is exported mainly from Conthey, Martigny and Saint-Maurice towards the districts rich in population as Monthey and Sion. Saint-Maurice exports 336 [MWh] to Monthey, while Conthey exports 382 [MWh] to Sion. Martigny which is adjacent to the districts of Monthey and Saint-Maurice exports 175 [GWh] to Saint-Maurice and 473 [GWh] to Conthey.
The Waste exchange is unfortunately mistaken, as only the districts of Brig, Sion and Monthey have incineration stations. The model is considering the possibility of burning waste in all districts. This aspect has to be considered when taking small regions, as districts.
By considering the Wood exchange, one can observe that the districts havong the biggest surface are exporting towards the population rich districts, which therefore have higher needs in high temperature heat and cannot cover their needs with the available potential.

The regionalized model allows to represent the energy conversion of the different districts. The district of Sion has been taken as example.
As seen before, the district of Sion has the highest population of Valais (56287 people) and a low surface, resulting in a high population density of 453.93 $[\frac{\text{people}}{\text{km}^2}]$, compared to the population density of Valais (74.62 $[\frac{\text{people}}{\text{km}^2}]$). The district of Sion can therefore be considered as urban as it is located in the bottom of the valley. This results in a high electricity need, which can't be covered by the district itself. Sion exports therefore 382 [MWh] electricity from Conthey. This import corresponds to 77.17 % of the Electricity used by the district of Sion.
The demand in high temepratute heat cannot be fully provided by own ressources. Wood (13 [MWh]) and Waste (6 [MWh]) are imported from other districts, corresponding to 17.81 % for Waste and 42.86 % for Wood.

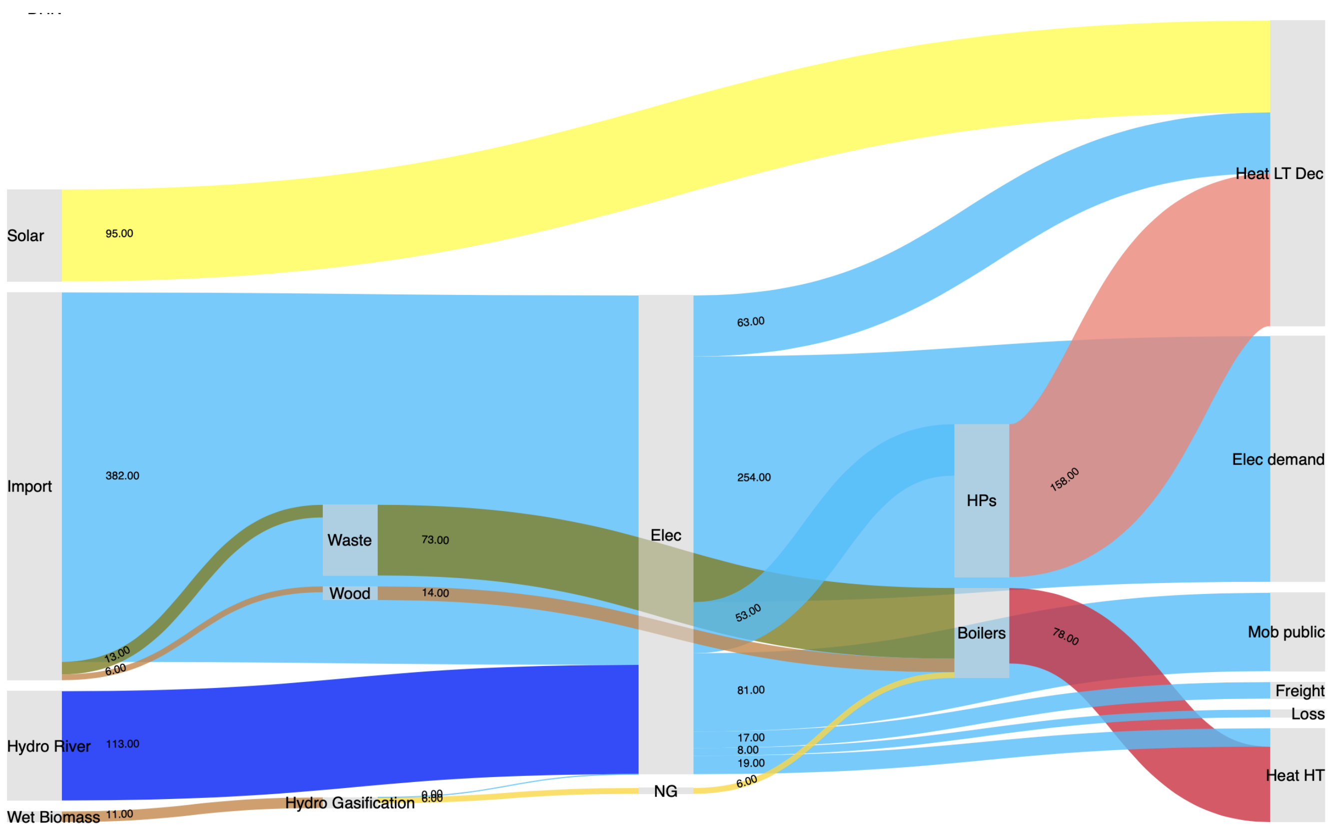
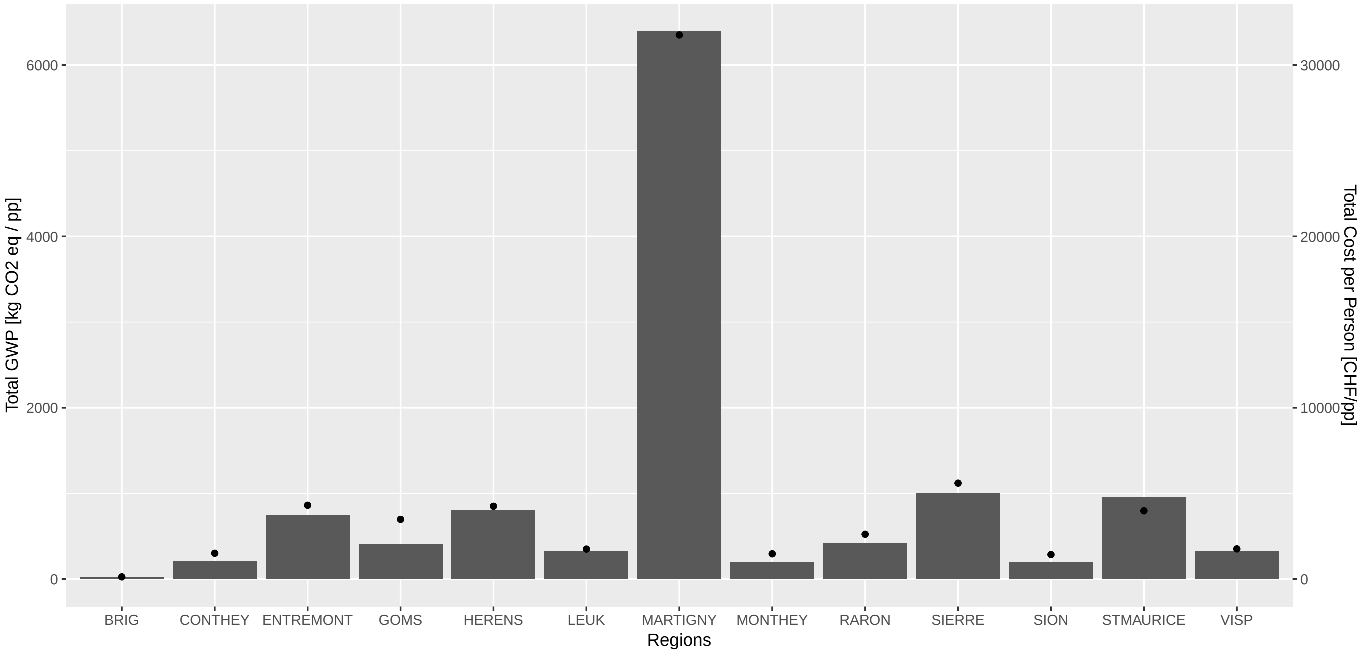


Figure 5: Sankey diagram VSES 2.0 2050, optimized on Total Cost (MWh). District of Sion.

8.2.3 Cost / GWP

The cost and the global warming potential (GWP) are calculated by the model and are summarized in the table below. The total cost is the sum of investment cost and operating costs. The shipping cost correpsonds to the amount of money the importing district has to pay to the exporting one.
The Total GWP is the sum of the GWP of constructing new technologies and the operating GWP, as for example the CO2 emissions when burning Wood or Gas.



Total GWP per person (bars) and Total cost per person (points) for each district of Valais according to VSES 2050 model.

By reducing these values to the number of people living in the district, one can observe that the district of Martigny has huge total cost per person compared to the rest of the districts. Martigny, being the most expensive district pays 244 times more than Brig.
This analysis is limited, as not the districts are in posession of the installations, but cantonal, or even federal companies. This assumption is therefore only valid, if the installations are all possessed by the correpsonding district.
These comparison allow to determine which districts are more producing than the others.

8.3 Switzerland 2050 SES 2.0

The regionalized Swiss Energyscope (SES 2.0) has been modelled, to generate the impact on Valais, when optmizing on a more global scope, here Switzerland. The data included has been described previously. Additionally the same sharing constraints sh_i as Moret used were introduced:

$$0.3 \leq sh_{mobility,public} \leq 0.5$$
$$0.4 \leq sh_{freight,train} \leq 0.8$$
$$sh_{DHN} \leq 0.6$$

These constraints allow to restrict the model to generate a "realizable" solution. The model does for example not take into account the distance between the houses, where it does not forcely makes sense to create a district heating network (DHN) to provide heat to an alpine housing. The first constraint has to do with the commodity of the population. People won't use only public transport. The value has therefore been restreined and the integration has been made into the R Markdown script `energyScopeCantons.Rmd`.

8.3.1 Energy conversion

From the Sankey diagram, it is visible that Photovoltaics, Hydropower and Wind are generating electricity, which is used to satisfy the electricity demand and mobility. A small part of electricity is used to generate high temperature heat.
Low Temperature heat is generated using electric powered heat pumps and geothermy at equal parts (17.205 [GWh]). It can be observed that the fraction of decentralized heat low temperature to DHN Low temperature is equal to 60%, correpsonding to the constraint set for sh_{DHN}.
Biomass is used to generate Biodiesel by Fischer-Tropsch (9.2 [GWh]) or to convert wet biomass into gas which is then transformed into heat and electricity by cogeneration.
Striking is the fact, that a part of wood (10.49 GWh) is directly burned in boilers to generate high temperature heat.

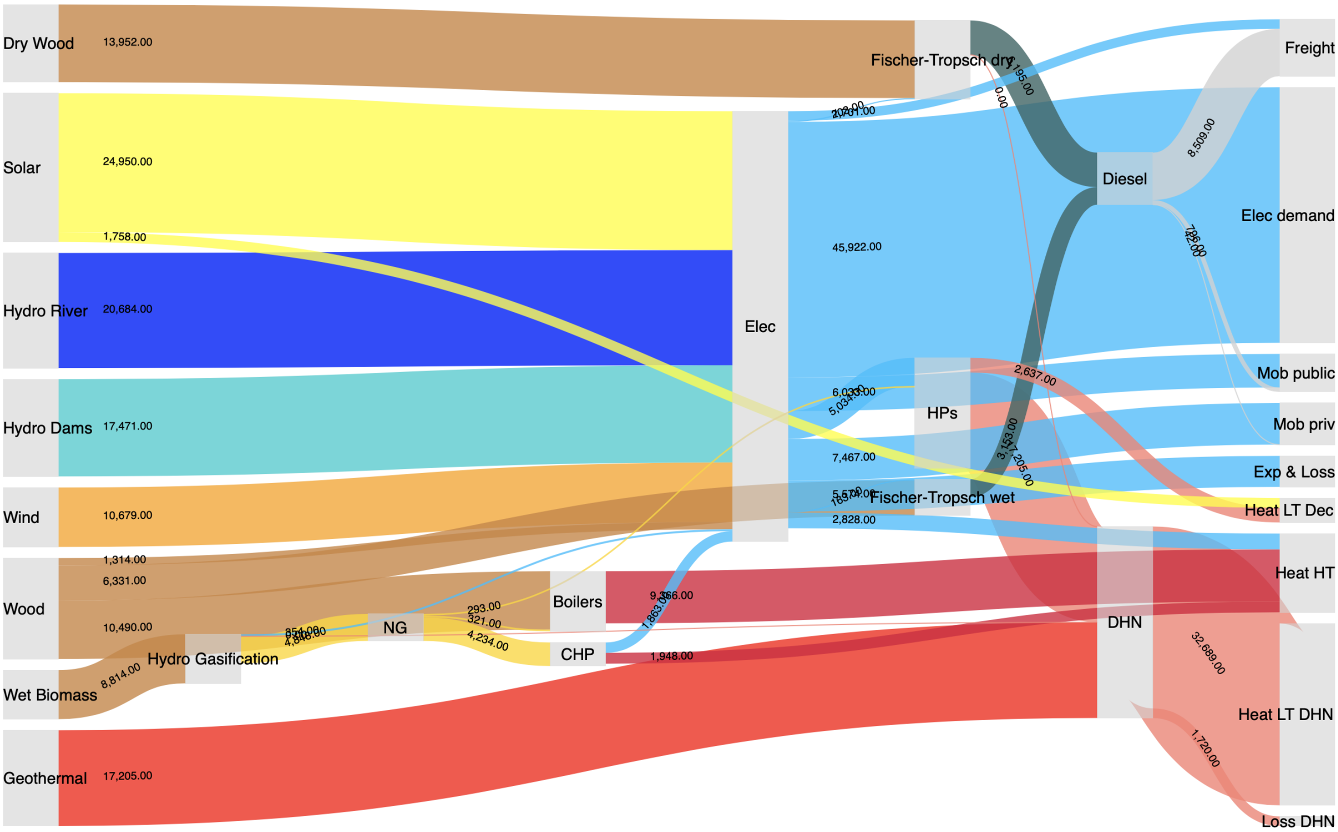


Figure 6: Sankey diagram SES 2.0 2050, Switzerland, optimized on Total Cost (MWh)

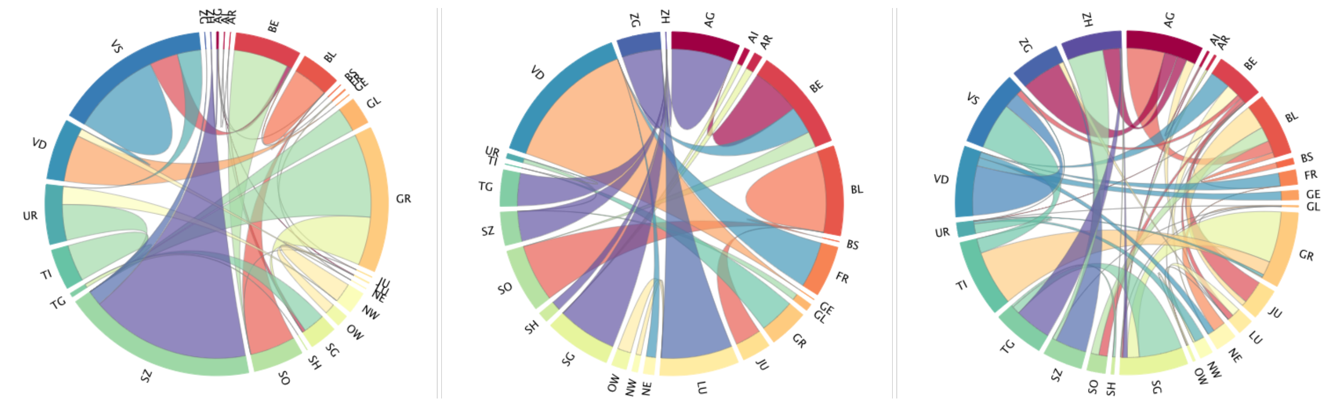


Figure 7: Chord diagram VSES 2.0 2050, optimized on Total Cost (MWh). Left Electricity, Middle Wood, Right Gas

8.3.2 Regionalization

The SES 2.0 is the regionalized model allowing to represent the flows exchanged. The chord diagrams for the electricity, wood and gas exchange are represented in the corresponding figure.
One can observe that the alpine cantons are exporting most of the electricity. Valais exports 10.332 GWh towards Vaud, Uri and Bern. Graubünden exports 9.683 GWh towards Schwyz and St. Gallen,. Striking is the quantity of electricity exported by the canton of Schwyz. In fact, Schwyz exports 11.73 GWh towards Zürich, being the canton with the highest population and energy demand. Schwyz imports a lot of electricity originated from Uri (2.61 GWh), Ticino (2.67 GWh), Glarus (1.78 GWh) and Graubünden (6.1 GWh), resulting in an import of 13.16 GWh. Schwyz is therfore a transit canton, allowing to transport electricity from the alpine cantons to the cantons in Mittelland.
Wood exchange between the cantons can be characterized by the surface and location of the canton. The cantons with a low population density and a high surface have a lot of forestal surfaces and therefore a big biomass potential. This wood can be used in cantons with high population density, as Zürich or Basel Stadt. This can be shown by the canton of Basel, which is plitted into two half-cantons. One is the rural one with bigger surface (Basel Landschaft) and the other one having a high population density, urban character and most of hte chamical industry. Wood is therfore flowing from Basel Landschaft to Basel Stadt (598 MWh).
The gas flow is represented in the third chord diagram. At first sight, lots of flows with no tendency is visible. In fact, some cantons even import and export from the same canton. This can be explained by a seasonal variation of the demand, combined with an over- or underproduction of Gas. This has to be investigated more in detail but outreaches our scope.

The main interest of this semester project is the canton of Valais, being a sub-region of the SES 2.0. The optimal solution to the cost minimization on Switzerland for the canton of Valais is visible in the respective Sankey diagram.
Most of the end-use demand is provided by electricity. Hydropower plants are generating 12.062 GWh of electric Energy. The rest is genreated using Wind power (1.35 GWh). From the total electricity produced, 10.332 GWh are exported to other regions (Uri, Bern, Vaud), corresponding to 77% of the electricity generated in Valais. Low termperature Heat is generated using electricity driven heat pumps and DHN originated additionally from geothermy.
In comparison to Switzerland, the private and public mobility are only electric drive, where freight is mostly Diesel-driven. This Biodiesel (249 MWh) is genreated by Fischer tropsch, using Wood.
Solar power is used only as thermal installation, to generate decentralized low temperature heat.

Table 14: Ressources used scenario SES 2.0 2050, canton of Valais

Ressources [GWh]	Diesel	Gasoline	Hydro Dams	Hydro River	Wind	Solar	Oil	NG	Wood	Waste	Wet Biomass	Dry Wood	El Export
SES 2050	0	0	7.645	4.417	1.351	0.07	0	0	1.003	0	0.278	0.52	-10.332

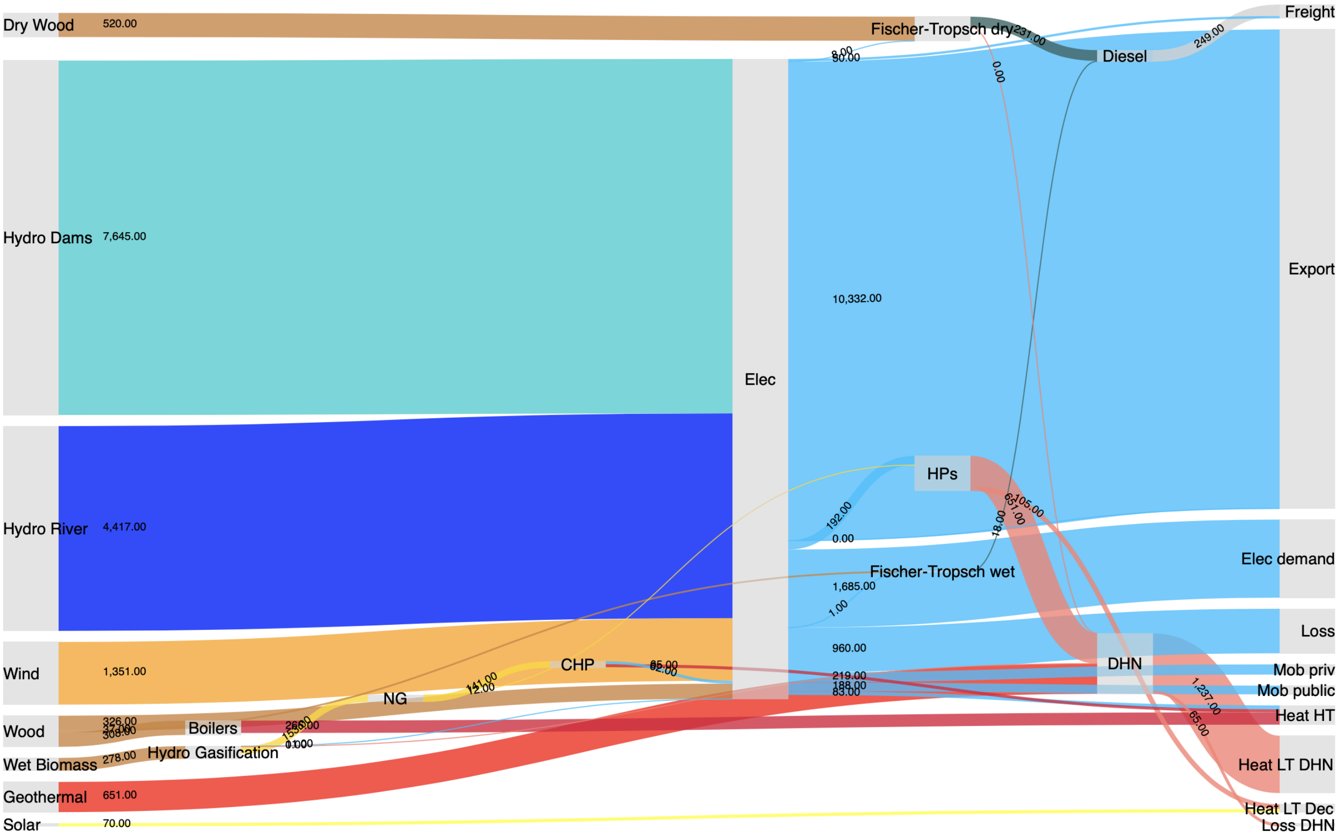
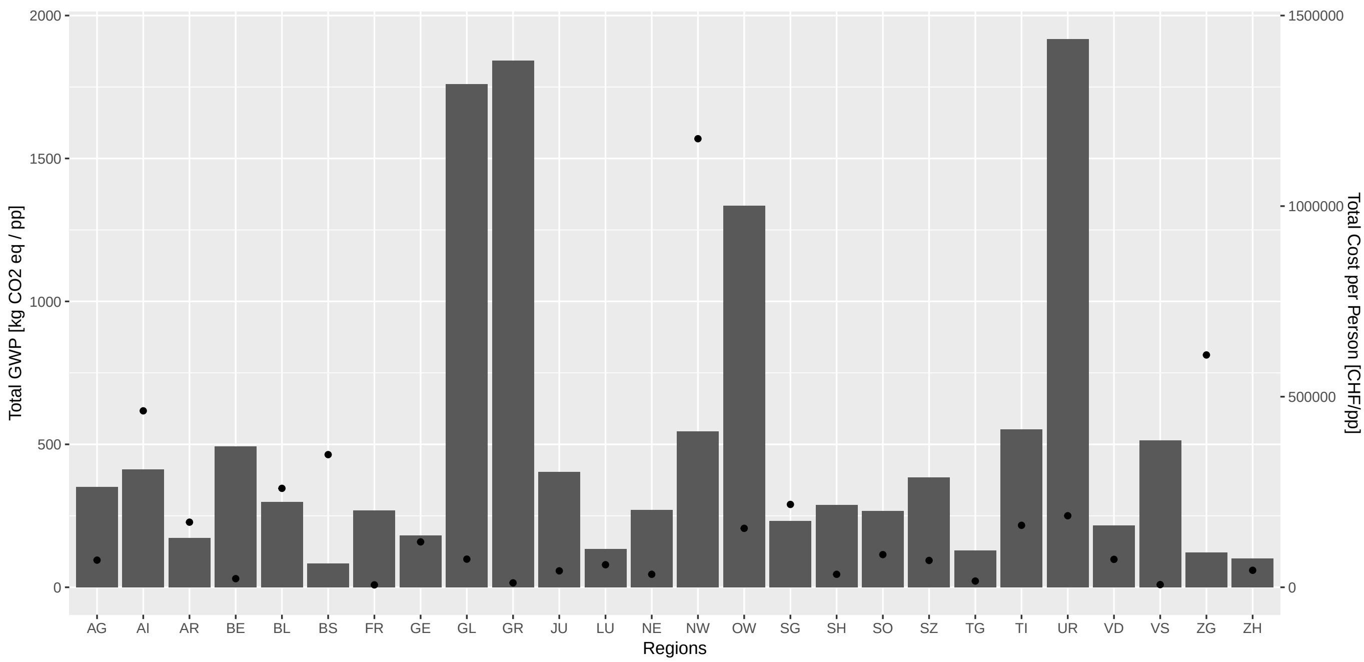


Figure 8: Sankey diagram SES 2.0 2050, Valais, optimized on Total Cost (MWh)

8.3.3 Cost / GWP

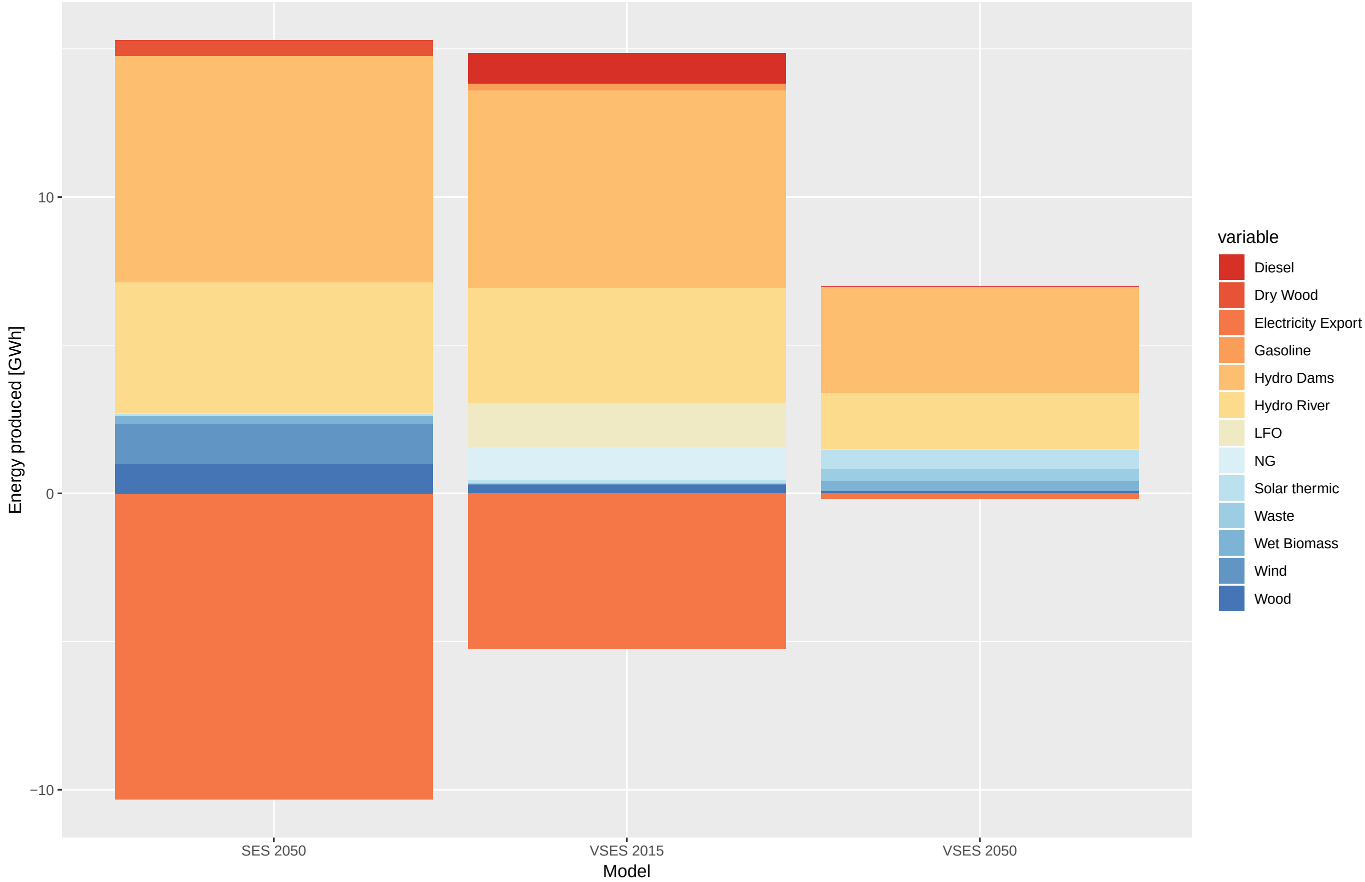


Total GWP per person (bars) and Total cost per person (points) for each canton of Switzerland according to SES 2.0 2050 model.

The cost for each canton is represented in the table in the appendix. The cost and GWP per person is visible in the bar diagram. The bars represent the GWP in [kg CO2 eq /pp] where the points represent the total cost per person in [CHF/ pp]. It is striking that the correlation beetween GWP and cost visible in the VSES 2.0 is no more given. In order to go deeper in the cantonal data, the respective Sankey diagram of the cantons has to be analyzed.
We will just look into the data for the canton of Valais. The cost per person is relatively low for Valais (6957.70 CHF/person). The GWP is at 513 kg CO2 equivalent per person. Cost and GWP are extremely low in comparison to the other cantons.

8.4 Discussion

It is now possible to compare the three scenarios for Valais.



Model comparison Energy mix canton of Valais.

The Energy mix of the three models is represented in the correpsonding figure. The graph is splitted in two parts. The positive values correspond to the Energy mix of Ressources. The negative part is the electricity exportesd. Striking is the summed ressources used. The SES 2050 model has a slightly higer energy mix sum than the reference case VSES 2015, but compared to the VSES 2050, the summed energy is 2 times more than the summed energy of VSES 2015.
The main difference in production is the difference in Hydropower use. SES 2050 needs a Hydropower generated energ of 12.062 [GWh], while VSES 2050 uses 5.492 [GWh].
This is due to the quantity of exported electricity. The model SES 2050 exports 10.332 [GWh], while the VSES 2050 is exporting only 192 [MWh].
The cost comaprison is following the same trend. The total cost of the VSES 2050 is at 1391 [MCHF], while the SES 2050 is more than double that value (3173 MCH). The exchange gains for Valais are for the SES 2050 of about 1025 [MCHF]. This corresponds to a final cost of 2112 [MCHF], being 52% higher than the VSES 2050 estimation. The canton of Valais has stated, that the cost of implementation of the energetic strategy will cost 1.5 Billion CHF [10]. In fact, this estimation covers with the total cost estimated by VSES 2050.
The use of solar power is only done by solar thermal and no photovoltaics are installed. This corresponds to the vision of the canton du Valais.
It all depends on which boundary to chose for the optmization. When taking to a more global scope, the results are no more the same and are varying strongly.

9 Conclusion

9.1 Valais 2050

The energetic strategy of the “Canton du Valais” has been shown to be feasible. The optimal solution to the VSES 2050 corresponds to the suggested solution given by the “Canton du Valais”. This model results in an minimization of the total cost for Valais.
It has been shown, that the optmial solution of Vlais does not correspond to the optimal solution of Switzerland. The main difference is due to the electricity export where the optmial solution of Valais exports more than 7 times less tha the optmial solution for Switzerland.
The cost of the second model for Valais is more than twice as high and the exchange gains cannot compensate this difference.
The Swiss federation has given the boundary conditions regarding the Energiestrategie 2050 and it is up to the cantons to implement these constraints to their territory. The ES35 is an example of implementaion of these boundary conditions but is not optimal for Switzerland, as 14% of the Swiss electricity. This sounds as not much, but this quantity would have to be compensated with renewable energies, which are temporarily fluctuating, inducing storage devices.

9.2 Limitations

The main limitation is the deletion of the integer variable. It is now possible to install power plants or installations at a fraction of their refernce size. This may have an impact for the installtion of a Biogenerator, Fischer-Tropsch, nuclear Power Plants or other installations with a refernce size higher than 500 MW.

The energetic end use of the districts of Valais is a harsh aproximation. Respective statistic values are missing.

Geothermal and Wind potential are estimated on a Swiss scale. Each downscaling includes errors, due to inconvenience of the topology, geology and so on of the respective region.

Solar potential has been estimated by Solardach.ch. Nevertheless, the GIS shape file has unresolved geometric errors which do not allow to apply the correct potential to the respective region.

The Gas transport exchange is estimated using data of a local provider. The estimation does not take into account the network construction.

The exchange of electricity is following the roads, which in reality is not the case. Furthermore, the losses are constant, not depending on the Voltage applied.

The solutions generated are not unique. They represent only one of several other optimal solutions. The Pareto-curve between Cost and GWp has not been realized and every optimization has been run on minimization of total cost.

The sensitivity analysis has not been realized. It is possible that when varying a variable, the solution suggested is changing strongly. In order to complement this analyzation, several optimal solutions have to be generated using Sobol and visualizing them into parallel coordinates.

9.3 R Markdown

R Markdown has been used in the sceond part of the project, as debugging and adaptation of models cannot be done with this tool. The model files have to be adapted in such a way that data is possible to implement.
As this tool is new in use at IPESE, the templates are under construction and more and more improvements can be implemented. Rmarkdown will neverthelss not be able to replace LaTeX for the report generation of long studies. R Markdown allows to generate html files where one can see how the things were coded and implemented, as done for the model launching of VSES 2.0 `energyScopeDistricts` and SES 2050 `energyScopeCantons`, where understanding of modelling is more important than results presentation.

9.4 Future developments

9.4.1 R Markdown

The adaptation to a new global region with other sub-regions has to be done witjout changing the code in the `.dat` file. This data file will has to be completely generated by the Rmd file, independent of the number of regions.
The adding of a new technology is in elaboration by Xiang and Lopez.

9.4.2 Visualization

A more developed chord diagram, in which the Sankey diagrams of each region are depicted and exchanging quantities with each other is in planning. This would allow to visualize all ressources, conversions, losses and exchanges on one single figure.
Ideally, the figure is interactive, meaning when clicking on a region, the figure shows the respective Sankey diagram as used in this report.

9.4.3 Grid

In order to reduce the calculation time, the grid tension can be split in three: low tension, mid tension and high tension. This would restrein the electricity exchange between the regions.

9.4.4 Renovation

To adapt the Energyscope model to future demands, two new aspects will be integrated into the current model.

1. The condition of the buildings plays an essential role. The aim is to integrate the data of the renovation status of Paul Stadler's thesis into the model.
2. Centralization and decentralization is an aspect that dictates the construction of and planning for urban and rural areas in the coming years. A special look is to be given to the Valais, where it is necessary to take into account the full and mountainous affection

9.4.4.1 Buildings

Buildings are defined by their status (i.e. their particular configuration). Paul Stadler clustered the entire Swiss built stock, based on the RegBL and defined 10 to 15 configurations / building types.
The question that currently arises is: how to summarize the built stock by a smaller number of categories. Clustering is the solution, with the advantages of desogn decisions and costs.
The current Energyscope model can be modified as follows:

$$Q_{t,h} = \sum_{t} \sum_{s,t} Q_{i,s,t,h}$$

Where $Q_{t,h}$ is the heat demand for heating h during the month m, which therefore becomes equal to the amount on the type of building t, as well as on the status s of the type of building t.
To facilitate implementation, $\sum_t \sum_{s,t} Q_{i,s,t,h}$ can be simplified by a factor of $f_{t,s}$ being the number of buildings in the s status. The model is therefore summarized as follows:

$$Q_{t,h} = \sum Q_{t,s,h} \cdot f_{t,s}$$

with $\sum f_{t,s} = 1$ and therefore dictating the demand for gas, as well as the use of solar panels. Care must therefore be taken to subtract these solar panels from an initial total shade.
The initial and necessary conditions for implementation are

$$Q_h = \sum Q_{t,h}$$

and

$$Q_h^0 = Q_{h,s=0}$$

9.4.4.2 DENSITY: CENTRALIZATION / DECENTRALIZATION

The second aspect is the implementation of density in the model. Density is a corollary to district heating (DHN) technology. Buildings must therefore be divided into two categories:

1. HLD
   1.1 CO_2
   1.2 district heating
2. individual

The model can therefore be adapted as follows

$$Q_h = Q_{h_{de}} \cdot (1 - f_c) + Q_{h_{ce}} \cdot f_c$$

with f_c being the factor of centralization, which will be parameterized (exponential price limiting the number of buildings in the centralization). In addition, the decentralized heat demand can be calculated as HLD, with the following modifications (for the use of CO_2): $Q_{h_c} = Q_{h_{de}}(T_0 = 17řC)$ and will therefore require electricity and a heat source to bring it to the desired temperature ($T_0 = 17řC$)

10 Appendixes

10.1 End use demand Switzerland

```
# Electricity table 3-43
El_house_PJ <- 50.43
El_service_PJ <- 61.25
El_industry_PJ <- 62.79

# Lighntning tables 3-48 to 3-52
Li_house_PJ <- 0.88
Li_service_PJ <- 7.50
Li_industry_PJ <- 3.22

# Heating demand 3.35 - 3.38 - 3.40
HT_house <- 0
LTSH_house <- 57.7
LTHW_house <- 25.8

HT_indu <- 77.03
LTSH_indu <- 11.41
LTHW_indu <- 5.95

HT_serv <- 8.08
LTSH_serv <- 30.70
LTHW_serv <- 14.12

Pass_trans <- 140300
freight_trans <- 41500

enduse50 <- t(round(data.frame(c(El_house_PJ,El_service_PJ,El_industry_PJ,0)/3600*10^6,
                              c(Li_house_PJ,Li_service_PJ,Li_industry_PJ,0)/3600*10^6,
                              c(HT_house,HT_serv,HT_indu,0/3600*10^6),
                              c(LTSH_house,LTSH_serv,LTSH_indu,0)/3600*10^6,
                              c(LTHW_house,LTHW_serv,LTHW_indu,0)/3600*10^6,
                              c(0,0,0,Pass_trans),
                              c(0,0,0,freight_trans))
                    ,2))
colnames(enduse50) <- c("Households","Services","Industry","Transportation")
row.names(enduse50) <- c("Electricity [GWh]","Lighting [GWh]","Heat High Temperature [GWh]",
                         "Surface Heating [GWh]","Hotwater [GWh]",
                         "Mobility Passenger [M pers km]","Mobility Freight [M t km]")
```

```
# Electricity table 3-43
El_house_PJ <- 37
El_service_PJ <- 40.2
El_industry_PJ <- 48.3

# Lighntning tables 3-48 to 3-52
Li_house_PJ <-5.7
Li_service_PJ <- 14.9
Li_industry_PJ <- 6.2

# Heating demand 3.35 - 3.38 - 3.40
HT_house <- 0
LTSH_house <- 13.90
```

```
LTHW_house <- 29.65

HT_indu <- 79.27
LTSH_indu <- 17.94
LTHW_indu <- 3.02

HT_serv <- 4.127
LTSH_serv <- 56.10
LTHW_serv <- 11.35

Pass_trans <- 121600
freight_trans <- 27660

enduse15 <- t(round(data.frame(c(El_house_PJ,El_service_PJ,El_industry_PJ,0)/3600*10^6,
                              c(Li_house_PJ,Li_service_PJ,Li_industry_PJ,0)/3600*10^6,
                              c(HT_house,HT_serv,HT_indu,0/3600*10^6),
                              c(LTSH_house,LTSH_serv,LTSH_indu,0)/3600*10^6,
                              c(LTHW_house,LTHW_serv,LTHW_indu,0)/3600*10^6,
                              c(0,0,0,Pass_trans),
                              c(0,0,0,freight_trans))
                  ,2))
colnames(enduse15) <- c("Households","Services","Industry","Transportation")
row.names(enduse15) <- c("Electricity [GWh]","Lighting [GWh]","Heat High Temperature [GWh]",
                         "Surface Heating [GWh]","Hotwater [GWh]",
                         "Mobility Passenger [M pers km]","Mobility Freight [M t km]")
```

10.2 End use demand Valais

```
data_canton <- read_excel("tables/ofs_data.xlsx")
dt <- data_canton
enduseVS15 <- enduse15
enduseVS15[,1] <- enduse15[,1]/as.double(dt[1,"surf_heat_2015"])*as.double(dt[which(dt$canton == "VS"),"su
enduseVS15[,2] <- enduse15[,2]/as.double(dt[1,"pop_2015"])*as.double(dt[which(dt$canton == "VS"),"pop_2015
enduseVS15[,3] <- enduse15[,3]/as.double(dt[1,"GDP_2015"])*as.double(dt[which(dt$canton == "VS"),"GDP_2015
enduseVS15[,4] <- enduse15[,4]/as.double(dt[1,"GDP_2015"])*as.double(dt[which(dt$canton == "VS"),"GDP_2015
enduseVS15 <- round(enduseVS15,2)

enduseVS50 <- enduse50
enduseVS50[,1] <- enduse50[,1]/as.double(dt[1,"surf_heat_2050"])*as.double(dt[which(dt$canton == "VS"),"su
enduseVS50[,2] <- enduse50[,2]/as.double(dt[1,"pop_2050"])*as.double(dt[which(dt$canton == "VS"),"pop_2050
enduseVS50[,3] <- enduse50[,3]/as.double(dt[1,"GDP_2050"])*as.double(dt[which(dt$canton == "VS"),"GDP_2050
enduseVS50[,4] <- enduse50[,4]/as.double(dt[1,"GDP_2050"])*as.double(dt[which(dt$canton == "VS"),"GDP_2050
enduseVS50 <- round(enduseVS50,2)
```

10.3 Ressources Valais 2050

```
resVS15 <- read_excel("tables/potential_limited.xlsx",sheet = "VS")
resVS50[5:6,2:ncol(resVS15)] <- resVS15[5:6,2:ncol(resVS15)]/as.double(dt[which(dt$canton == "VS"),"surf_h
resVS50[5:6,2:ncol(resVS15)] <- resVS50[5:6,2:ncol(resVS15)]*1.12
```

10.4 Restreined ressources Switzerland 2015

Table 15: Restreined ressources potential Switzerland (2015). Regionalized according cantons.

...1	Waste [GWh]	Biomass dry [GWh]	Biomass wet [GWh]	Wood [GWh]	Solar thermic [GWh]	PV [GWh]	Wind [GWh]	Hydro Dam [GW]	Hydro River [GW]
CH	11142.00	13951.97	8813.57	10291.00	8218.09	54221.48	9800.00	8.07	3.98
ZH	1951.31	1217.42	548.05	1186.00	1301.82	9348.37	410.39	0.00	0.10
BE	1370.64	2804.37	1632.81	1875.00	920.00	6606.50	1414.53	0.67	0.31
LU	534.27	783.19	998.04	614.00	360.46	2588.46	354.50	0.00	0.01
UR	49.14	78.20	33.13	98.00	32.43	232.88	255.51	0.16	0.29
SZ	207.25	337.69	239.96	246.00	147.78	1061.23	215.56	0.05	0.06
OW	49.96	206.60	102.04	115.00	34.30	246.34	116.44	0.10	0.04
NW	57.36	89.22	71.61	99.00	40.88	293.57	65.53	0.01	0.03
GL	54.21	112.37	39.26	118.00	39.58	284.26	162.70	0.39	0.11
ZG	161.66	83.42	185.26	134.00	113.14	812.43	56.67	0.00	0.01
FR	407.37	597.91	746.99	345.00	268.96	1931.38	396.61	0.13	0.07
SO	357.82	769.13	184.68	283.00	262.22	1882.97	187.65	0.00	0.10
BS	259.13	103.14	47.80	147.00	163.78	1176.13	8.80	0.00	0.00
BL	381.50	383.46	128.89	278.00	270.03	1939.10	122.85	0.00	0.13
SH	107.87	192.09	66.79	109.00	80.88	580.81	70.86	0.00	0.03
AR	73.51	108.64	121.82	130.00	54.51	391.43	57.67	0.00	0.00
AI	21.63	67.08	91.47	47.00	14.69	105.49	40.95	0.00	0.00
SG	673.07	968.82	858.58	804.00	467.79	3359.21	480.79	0.09	0.07
GR	266.93	583.14	310.08	501.00	181.58	1303.92	1686.58	1.90	0.61
AG	871.14	958.54	433.11	722.00	642.45	4613.44	333.22	0.00	0.48
TG	356.32	482.74	555.45	403.00	267.71	1922.44	235.21	0.00	0.01
TI	474.31	240.06	78.96	432.00	334.01	2398.52	667.61	1.01	0.28
VD	1025.83	1413.84	513.61	590.00	657.66	4722.61	762.46	0.03	0.18
VS	386.82	307.16	401.65	490.00	1656.40	3704.04	1240.14	3.42	0.91
NE	241.47	341.01	153.43	154.00	158.37	1137.24	190.63	0.00	0.05
GE	642.54	132.47	103.25	261.00	369.26	2651.65	67.04	0.00	0.15
JU	98.15	377.43	290.90	110.00	64.58	463.73	199.11	0.00	0.01

10.5 Cost / GWP cantons of Switzerland

Table 16: Cost and CO2 emissions of each canton of Switzerland according model SES 2.0 2050.

Regions	Total Cost [MCHF]	Total GWP [kt CO2 eq]	Shipping Cost [MCHF]
ZH	86448.942	193.814821	1332.530471
BE	27703.267	603.443249	-288.697307
LU	30517.070	69.324898	176.835910
UR	6836.418	69.870152	-223.232434
SZ	13938.878	76.161888	17.436043
OW	6745.686	58.202790	-85.795539
NW	53329.053	24.674416	-14.939517
GL	3449.272	82.256593	-181.016109
ZG	96760.009	19.212546	133.525898
FR	2948.380	125.362480	-33.172842
SO	28583.334	89.192735	38.978277
BS	75353.033	18.077899	313.871149
BL	83953.843	96.424473	77.696429
SH	3434.719	29.011445	18.451715
AR	10416.036	10.529654	17.972258
AI	7555.859	6.729615	-2.901156
SG	133340.910	142.569423	138.362210
GR	2551.571	404.451447	-981.437729
AG	62801.310	309.350036	15.116803
TG	6007.280	47.227655	109.611368
TI	72068.397	244.801103	-240.652454
VD	78363.989	230.617218	217.133977
VS	3173.289	234.227015	-1025.960366
NE	7219.702	57.351070	56.833439
GE	74669.080	113.865548	431.578389
JU	3623.217	33.894583	-18.982020

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