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Employment impacts of renewable energy deployment in Switzerland

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List of abbreviations

ACI:	annual capacity installed
AG:	Aargau
AI:	Appenzell Innerrhoden
AR:	Appenzell Ausserrhoden
BE:	Bern
BL:	Basel-Landschaft
BS :	Basel-Stadt
CE:	conventional energy
CET:	conventional energy technologies
CGE:	computable general equilibrium
CHP:	combined heat and power
EDGE:	Enabling Decentralized renewable GEneration in the Swiss cities, midlands, and the Alps
FR:	Fribourg
FTE:	fulltime equivalent
GE:	Geneva
GL:	Glarus
GR:	Graubünden
GWh:	gigawatt hour
IGCC:	integrated gasification combined cycle
IO:	input-output
IOT:	input-output table
JASM:	Joint Activity Scenarios and Modelling
JU:	Jura
LU:	Luzern
MSW:	municipal solid waste
MW:	megawatt
n.s:	not specified
NE:	Neuchâtel
NW:	Nidwalden
O&M:	operation and maintenance
OW:	Obwalden
PV:	photovoltaic
RE:	renewable energy
RET:	renewable energy technologies
RETD:	renewable energy technology deployment
SG:	St. Gallen
SH:	Schaffhausen
SO:	Solothurn
STATENT:	structural statistic of enterprises (Federal Statistical Office)
SWEET:	SWiss Energy research for the Energy Transition
SZ:	Schwyz
TG:	Thurgau
TI:	Ticino
TWh	terawatt hour
UR:	Uri
VD:	Vaud
VS:	Valais
ZG:	Zug
ZH:	Zürich

Summary

The transition towards a fully renewable energy system in Switzerland will have broad socio-economic implications. Apart from the overall economic impacts, SWEET EDGE aims at analysing the distributional impacts of the energy transition, including differences among regions in Switzerland. Within the EDGE project, Heinisch et al. (2023) have analysed a variety of scenarios with high shares of renewable electricity generation in Switzerland with three different energy system models. The aim of this report is to estimate the national and regional employment impacts of these scenarios as a contribution to the analysis of the distributional impacts of the energy transition.

We apply a methodological approach that combines techno-economic data with input-output-modelling. Starting with results of the energy models on power plant and storage capacities in 2035, we derive the development of investment, O&M and dismantling expenditures between 2021 and 2035, based on technology specific cost data and projections. The expenditures are distributed to cost components and used to generate values for imports and domestic economic activities. Industry specific employment intensities are used to calculate direct employment and an input-output model is used to estimate indirect employment in the supply chain activities, induced by constructing, operation and dismantling of power plants. The approach is dynamic in that it is based on time series of power plant capacities and it reflects changing costs and cost structures and increasing labour productivity over time.

In this report we analyse the consequences of a transition of power generation to a system with high shares of renewables for employment in Switzerland. Our starting point are the results of three energy system models for four main scenarios with several scenario variants (Heinisch et al. 2023). The scenarios mainly differ with regard to the ambition level of renewable electricity targets. Nuclear power is assumed to be phased out by 2035 and electricity generation is mainly replaced by new renewable energy technologies. Hydro power generation is not assumed to be expanded substantially. In the scenarios with lower targets, net electricity imports are significant. Thus, the scenarios mainly depict a transition from a few nuclear power plants to many decentralised power generation units with varying degrees of net electricity imports. In all scenarios, PV plants have the largest shares in the expansion of new renewables. The contribution of biomass and wind power plants varies between models and scenarios, but remains limited. Pumped hydro power plants remain by far the most important storage technology with limited capacity expansion of batteries in some scenario variants. Investment in grid expansion also is negligible.

In our calculations, we assume a linear expansion of power generation capacities between the models' base years and the target year 2035. This seems realistic, as the current annual expansion of PV plant capacities already exceeds the average expansion assumed in the most ambitious scenario. Our annual results thus reflect this assumption and not the actual development of employment required for power generation. The actual development of employment in every future year can, of course, deviate from this smooth path. Furthermore, we assume that labour supply can accommodate the additional demand, also at the local level. This implies that the job requirements that we compute become actual job creations and employment levels. We shall not make this distinction in this report.

At the national level, employment induced by power generation lies between 10 000 and 18 000 fulltime equivalents (average of the years 2021 – 2035, depending on the model and scenario). It increases with the ambition level of the renewable electricity target in the scenarios, since more construction of new PV and other power plants is initiated. Over time, the larger capacities also lead to more employment in operation and maintenance of existing plants. Employment per unit of added capacity will decrease due to decreasing investment costs of PV plants and increasing labour productivity. On the other hand, employment in nuclear power plants decreases due to the phase-out. Yet, the employment decrease is delayed beyond the year 2035 due to the long post-operation and dismantling period, sustaining employment for over a decade after the shutdown of nuclear power plants. Due to the strong capacity expansion, most of the generated jobs are linked to the construction of new plants. Employment for the operation of power plants and in suppliers for O&M is lower, but still substantial. Jobs in fuel supply (forestry and gas supply) are significantly lower. Jobs in dismantling of nuclear power plants are significant with almost 2 000 jobs in 2035.

At the regional level, we report results for cantons and EDGE regions (cities, midlands, alps). The regional employment impacts depend on the extent to which regions contain power plant locations and participate in the supply chains induced by constructing, operating and dismantling power plants. The relative importance of employment also depends on the size of regional economies. The regional employment impacts differ strongly between models and scenarios. Employment generally increases with the ambition level of the scenarios, but the regional distribution differs between the models. It tends to be higher for the Nexus-e model than for the EXPANSE

and the OREES model, since capacity expansion tends to be higher. It also tends to be more evenly distributed across cantons, since Nexus-e less strongly optimises for the most productive plant sites. The results at the cantonal level show that the shares of employment induced by power generation in total employment are higher for cantons in the alps (Glarus, Graubünden, Uri and Valais), that profit from the locations of renewable and for cantons that host nuclear power plants. It is also evident that in the long run, after the end of the dismantling period, the employment in the cantons of Aargau and Solothurn, that is related to power plants and their supply chains, will decrease due to the energy transition. In most other cantons, it will increase, so that employment in this small segment of the energy sector will be more evenly distributed across cantons.

For the EDGE regions, our results show that most of the jobs related to power generation will be generated in the cities, but the share of these jobs in total regional employment will be higher for the alps and the midlands.

Our results only reflect the time between 2021 and 2035, since the results of the energy models refer to 2035. They thus only provide a part of the employment impacts of the energy transition that will continue strongly after 2035. Our reference period is characterised by a strong increase in renewable power generation capacities that mainly induces employment for the construction of new power plants and thus temporary jobs that will decline when the period of strong capacity increases is over and when replacement of existing power plants. In the electricity sector, the energy transition is also characterised by a shift of jobs in operation of power plants to jobs in construction of new plants and with suppliers to power plants.

The methodological approach that we have used is flexible in that it can include the available information on the technology-specific supply chains and can be adapted to different data availability situations. When dedicated employment numbers are available for specific technologies, they can be integrated. We have for example included employment factors for nuclear power plants and fuel supply, based on company reports and official statistics. The approach allows to comprehensively cover the whole life cycle of power plants, from construction to dismantling, and the activities in the respective supply chains. Regarding estimates of regional employment, the approach makes use of information on power plant locations. A significant share of regional employment can be derived from this information and the characteristics of the induced economic activities. For the segment of direct suppliers to construction, O&M and dismantling of power plants, some uncertainty remains. Here, a survey of companies active in the energy field and their regional distribution would improve the accuracy of the results. Such a survey was not possible in this project.

Our results only refer to a small segment of the energy transition, namely the supply side of electricity generation. Heat generation, mobility and changes on the demand side have not been considered yet. The methodological approach applied in this report can generally also be applied for other parts of the energy transition to estimate their consequences for employment.

Zusammenfassung

Der Übergang zu einem vollständig erneuerbaren Energiesystem in der Schweiz wird weitreichende sozioökonomische Auswirkungen haben. Neben den gesamtwirtschaftlichen Auswirkungen zielt SWEET EDGE darauf ab, die Verteilungseffekte der Energiewende zu analysieren, einschliesslich der Unterschiede zwischen den Regionen der Schweiz. Im Rahmen des EDGE-Projekts haben Heinisch et al. (2023) mit drei verschiedenen Energiesystemmodellen eine Vielzahl von Szenarien mit hohen Anteilen erneuerbarer Stromerzeugung in der Schweiz analysiert. Ziel dieses Berichts ist es, die nationalen und regionalen Auswirkungen dieser Szenarien auf die Beschäftigung zu schätzen, um einen Beitrag zur Analyse der Verteilungseffekte der Energiewende zu leisten.

Wir wenden einen methodischen Ansatz an, der techno-ökonomische Daten mit Input-Output-Modellierung kombiniert. Ausgehend von den Ergebnissen der Energiemodelle zu Kraftwerks- und Speicherkapazitäten im Jahr 2035 leiten wir die Entwicklung der Investitions-, Betriebs- und Wartungs- sowie Rückbaukosten zwischen 2021 und 2035 ab, basierend auf technologiespezifischen Kostendaten und Prognosen. Die Ausgaben werden auf Kostenkomponenten verteilt und zur Ermittlung von Werten für Importe und inländische Wirtschaftstätigkeiten herangezogen. Zur Berechnung der direkten Beschäftigung werden branchenspezifische Beschäftigungsintensitäten verwendet, und zur Schätzung der indirekten Beschäftigung in den Lieferkettenaktivitäten, die durch den Bau, den Betrieb und den Rückbau von Kraftwerken induziert wird, wird ein Input-Output-Modell verwendet. Der Ansatz ist dynamisch, da er auf Zeitreihen der Kraftwerkskapazitäten basiert und die sich im Laufe der Zeit verändernden Kosten und Kostenstrukturen sowie die steigende Arbeitsproduktivität widerspiegelt.

In diesem Bericht analysieren wir die Folgen einer Umstellung der Stromerzeugung auf ein System mit einem hohen Anteil an erneuerbaren Energien für die Beschäftigung in der Schweiz. Ausgangspunkt sind die Ergebnisse von drei Energiesystemmodellen für vier Hauptszenarien mit mehreren Szenariovarianten (Heinisch et al. 2023). Die Szenarien unterscheiden sich hauptsächlich hinsichtlich des Ambitionsniveaus der Ziele für erneuerbaren Strom. Es wird davon ausgegangen, dass die Kernenergie bis 2035 eingestellt wird und die Stromerzeugung hauptsächlich durch neue Technologien für erneuerbare Energien ersetzt wird. Es wird nicht davon ausgegangen, dass die Stromerzeugung aus Wasserkraft wesentlich ausgebaut wird. In den Szenarien mit niedrigeren Zielen sind die Netto-Stromimporte erheblich. Somit zeigen die Szenarien hauptsächlich einen Übergang von wenigen Kernkraftwerken zu vielen dezentralen Stromerzeugungseinheiten mit unterschiedlichem Umfang an Netto-Stromimporten. In allen Szenarien haben PV-Anlagen den grössten Anteil am Ausbau neuer erneuerbarer Energien. Der Beitrag von Biomasse- und Windkraftanlagen variiert zwischen den Modellen und Szenarien, bleibt jedoch begrenzt. Pumpspeicherkraftwerke bleiben bei weitem die wichtigste Speichertechnologie, wobei der Kapazitätsausbau von Batterien in einigen Szenariovarianten begrenzt ist. Die Investitionen in den Netzausbau sind ebenfalls vernachlässigbar.

In unseren Berechnungen gehen wir von einem linearen Ausbau der Stromerzeugungskapazitäten zwischen den Basisjahren der Modelle und dem Zieljahr 2035 aus. Dies erscheint realistisch, da der derzeitige jährliche Ausbau der PV-Anlagenkapazitäten bereits über dem durchschnittlichen Ausbau liegt, der im ambitioniertesten Szenario angenommen wird. Unsere Jahresergebnisse spiegeln daher diese Annahme wider und nicht die tatsächliche Entwicklung der für die Stromerzeugung erforderlichen Beschäftigung. Die tatsächliche Entwicklung der Beschäftigung in jedem zukünftigen Jahr kann natürlich von diesem glatten Verlauf abweichen. Darüber hinaus gehen wir davon aus, dass das Arbeitskräfteangebot den zusätzlichen Bedarf auch auf lokaler Ebene decken kann. Dies bedeutet, dass die von uns berechneten Arbeitsplatzanforderungen zu tatsächlichen Arbeitsplatzschaffungen und Beschäftigungsniveaus führen. In diesem Bericht werden wir diese Unterscheidung nicht treffen.

Auf nationaler Ebene liegt die durch die Stromerzeugung induzierte Beschäftigung zwischen 10 000 und 18 000 Vollzeitäquivalenten (Durchschnitt der Jahre 2021–2035, je nach Modell und Szenario). Sie steigt mit dem Ambitionsniveau des Ziels für erneuerbaren Strom in den Szenarien, da mehr Neubauten von PV- und anderen Kraftwerken initiiert werden. Im Laufe der Zeit führen die grösseren Kapazitäten auch zu mehr Beschäftigung im Betrieb und in der Wartung bestehender Anlagen. Die Beschäftigung pro Einheit zusätzlicher Kapazität wird aufgrund sinkender Investitionskosten für PV-Anlagen und steigender Arbeitsproduktivität zurückgehen. Auf der anderen Seite sinkt die Beschäftigung in Kernkraftwerken aufgrund des Ausstiegs. Der Beschäftigungsrückgang verzögert sich jedoch aufgrund der langen Nachbetriebs- und Stilllegungsphase bis über das Jahr 2035 hinaus, wodurch die Beschäftigung nach der Stilllegung der Kernkraftwerke noch über ein Jahrzehnt lang aufrechterhalten wird. Aufgrund des starken Kapazitätsausbaus stehen die meisten der geschaffenen Arbeitsplätze im Zusammenhang mit dem Bau neuer Anlagen. Die Beschäftigung im Betrieb von Kraftwerken und bei Zulieferern für Betrieb und Wartung ist geringer, aber immer noch beträchtlich. Die Zahl der Arbeitsplätze in der

Brennstoffversorgung (Forstwirtschaft und Gasversorgung) ist deutlich geringer. Die Zahl der Arbeitsplätze im Rückbau von Kernkraftwerken ist mit fast 2'000 Stellen im Jahr 2035 erheblich.

Auf regionaler Ebene berichten wir über Ergebnisse für die Kantone und die drei EDGE-Regionen (Städte, Mittelland, Alpen). Die regionalen Auswirkungen auf die Beschäftigung hängen davon ab, inwieweit Regionen Kraftwerksstandorte beherbergen und an den Lieferketten beteiligt sind, die durch den Bau, den Betrieb und den Rückbau von Kraftwerken entstehen. Die relative Bedeutung der Beschäftigung auf regionaler Ebene hängt auch von der Grösse der regionalen Wirtschaft ab. Die regionalen Auswirkungen auf die Beschäftigung unterscheiden sich stark zwischen den Modellen und Szenarien. Die Beschäftigung steigt im Allgemeinen mit dem Ambitionsniveau der Szenarien, aber die regionale Verteilung unterscheidet sich zwischen den Modellen. Sie ist beim Nexus-e-Modell tendenziell höher als beim EXPANSE- und beim OREES-Modell, da die Kapazitätserweiterung tendenziell höher ist. Sie ist auch tendenziell gleichmässiger über die Kantone verteilt, da Nexus-e weniger stark auf die produktivsten Kraftwerksstandorte optimiert. Die Ergebnisse auf Kantonsebene zeigen, dass der Anteil der durch die Stromerzeugung induzierten Beschäftigung an der Gesamtbeschäftigung in den Alpenkantonen (Glarus, Graubünden, Uri und Wallis) höher ist, die von den Standorten erneuerbarer Energien profitieren, sowie in Kantonen, in denen Kernkraftwerke stehen. Es ist auch offensichtlich, dass langfristig, nach dem Ende der Stilllegungsphase, die Beschäftigung in den Kantonen Aargau und Solothurn, die mit Kraftwerken und deren Lieferketten zusammenhängt, aufgrund der Energiewende zurückgehen wird. In den meisten anderen Kantonen wird sie zunehmen, sodass die Beschäftigung in diesem kleinen Segment des Energiesektors gleichmässiger über die Kantone verteilt sein wird.

Für die EDGE-Regionen zeigen unsere Ergebnisse, dass die meisten Arbeitsplätze im Zusammenhang mit der Stromerzeugung in den Städten entstehen werden, aber der Anteil dieser Arbeitsplätze an der gesamten regionalen Beschäftigung wird in den Alpen und im Mittelland höher sein.

Unsere Ergebnisse spiegeln nur den Zeitraum zwischen 2021 und 2035 wider, da sich die Ergebnisse der Energiemodelle auf das Jahr 2035 beziehen. Sie geben somit nur einen Teil der Auswirkungen der Energiewende auf die Beschäftigung wieder, die nach 2035 weiterhin stark sein werden. Unser Referenzzeitraum ist durch einen starken Anstieg der Kapazitäten zur Stromerzeugung aus erneuerbaren Energien gekennzeichnet, der vor allem Arbeitsplätze für den Bau neuer Kraftwerke und damit befristete Arbeitsplätze schafft, die nach Ablauf der Phase des starken Kapazitätsausbaus und beim Ersatz bestehender Kraftwerke wieder abnehmen werden. Im Elektrizitätssektor ist die Energiewende auch durch eine Verlagerung von Arbeitsplätzen im Betrieb von Kraftwerken hin zu Arbeitsplätzen im Bau neuer Anlagen und bei Zulieferern für Kraftwerke gekennzeichnet.

Der von uns verwendete methodische Ansatz ist flexibel, da er die verfügbaren Informationen zu den technologiespezifischen Lieferketten einbeziehen und an unterschiedliche Datenverfügbarkeiten anpassen kann. Wenn spezifische Beschäftigungszahlen für bestimmte Technologien verfügbar sind, können diese integriert werden. So haben wir beispielsweise Beschäftigungsfaktoren für Kernkraftwerke und die Brennstoffversorgung auf der Grundlage von Unternehmensberichten und amtlichen Statistiken berücksichtigt. Der Ansatz ermöglicht es, den gesamten Lebenszyklus von Kraftwerken vom Bau bis zum Rückbau sowie die Aktivitäten in den jeweiligen Lieferketten umfassend abzudecken. Bei der Schätzung der regionalen Beschäftigung nutzt der Ansatz Informationen über die Standorte der Kraftwerke. Ein erheblicher Teil der regionalen Beschäftigung lässt sich aus diesen Informationen und den Merkmalen der induzierten wirtschaftlichen Aktivitäten ableiten. Für den Bereich der direkten Zulieferer für den Bau, den Betrieb und die Stilllegung von Kraftwerken bleibt eine gewisse Unsicherheit bestehen. Hier würde eine Umfrage unter Unternehmen, die im Energiebereich tätig sind, und deren regionale Verteilung die Genauigkeit der Ergebnisse verbessern. Eine solche Umfrage war im Rahmen dieses Projekts nicht möglich.

Unsere Ergebnisse beziehen sich nur auf einen kleinen Teilbereich der Energiewende, nämlich die Angebotsseite der Stromerzeugung. Die Wärmeerzeugung, die Mobilität und Veränderungen auf der Nachfrageseite wurden noch nicht berücksichtigt. Der in diesem Bericht angewandte methodische Ansatz kann im Allgemeinen auch für andere Teile der Energiewende angewendet werden, um deren Auswirkungen auf die Beschäftigung abzuschätzen.

Résumé

La transition vers un système énergétique entièrement renouvelable en Suisse aura de vastes implications socio-économiques. Outre les impacts économiques globaux, SWEET EDGE vise à analyser les impacts distributifs de la transition énergétique, y compris les différences entre les régions de Suisse. Dans le cadre du projet EDGE, Heinisch et al. (2023) ont analysé divers scénarios prévoyant une part élevée de production d'électricité renouvelable en Suisse à l'aide de trois modèles de systèmes énergétiques différents. L'objectif de ce rapport est d'estimer les impacts nationaux et régionaux de ces scénarios sur l'emploi afin de contribuer à l'analyse des effets distributifs de la transition énergétique.

Nous appliquons une approche méthodologique qui combine des données technico-économiques avec une modélisation des entrées-sorties. À partir des résultats des modèles énergétiques sur les capacités des centrales électriques et de stockage en 2035, nous déduisons l'évolution des dépenses d'investissement, d'exploitation et de démantèlement entre 2021 et 2035, sur la base de données et de projections de coûts spécifiques à chaque technologie. Les dépenses sont réparties entre les différents éléments de coût et utilisées pour générer des valeurs pour les importations et les activités économiques nationales. Les intensités d'emploi spécifiques à l'industrie sont utilisées pour calculer l'emploi direct et un tableau d'entrées-sorties est utilisé pour estimer l'emploi indirect dans les activités de la chaîne d'approvisionnement, induit par la construction, l'exploitation et le démantèlement des centrales électriques. L'approche est dynamique dans la mesure où elle repose sur des séries chronologiques des capacités des centrales électriques et reflète l'évolution des coûts et des structures de coûts ainsi que l'augmentation de la productivité du travail au fil du temps.

Dans le présent rapport, nous analysons les conséquences d'une transition vers un système de production d'électricité à forte part d'énergies renouvelables sur l'emploi en Suisse. Nous partons des résultats de trois modèles de systèmes énergétiques pour quatre scénarios principaux avec plusieurs variantes (Heinisch et al. 2023). Les scénarios diffèrent principalement en ce qui concerne le niveau d'ambition des objectifs en matière d'électricité renouvelable. L'énergie nucléaire devrait être supprimée d'ici 2035 et la production d'électricité devrait être principalement remplacée par de nouvelles technologies d'énergie renouvelable. La production d'énergie hydraulique ne devrait pas connaître d'augmentation substantielle. Dans les scénarios avec des objectifs moins ambitieux, les importations nettes d'électricité sont importantes. Ainsi, les scénarios décrivent principalement une transition de quelques centrales nucléaires vers de nombreuses unités de production d'électricité décentralisées avec des niveaux variables d'importations nettes d'électricité. Dans tous les scénarios, les centrales photovoltaïques ont la plus grande part dans l'expansion des nouvelles énergies renouvelables. La contribution des centrales à biomasse et éoliennes varie selon les modèles et les scénarios, mais reste limitée. Les centrales hydroélectriques à accumulation par pompage restent de loin la technologie de stockage la plus importante, avec une expansion limitée de la capacité des batteries dans certaines variantes de scénarios. Les investissements dans l'expansion du réseau sont également négligeables.

Dans nos calculs, nous supposons une expansion linéaire des capacités de production d'électricité entre les années de référence des modèles et l'année cible 2035. Cela semble réaliste, car l'expansion annuelle actuelle des capacités des centrales photovoltaïques dépasse déjà l'expansion moyenne supposée dans le scénario le plus ambitieux. Nos résultats annuels reflètent donc cette hypothèse et non l'évolution réelle de l'emploi nécessaire à la production d'électricité. L'évolution réelle de l'emploi au cours de chaque année future peut bien sûr s'écarter de cette trajectoire régulière. En outre, nous postulons que l'offre de main-d'œuvre peut répondre à la demande supplémentaire, y compris au niveau local. Cela implique que les besoins en main-d'œuvre que nous calculons se traduisent effectivement en création et niveaux d'emplois correspondants. Nous ne ferons pas cette distinction dans le présent rapport.

Au niveau national, l'emploi additionnel induit par la production d'électricité se situe entre 10 000 et 18 000 équivalents temps plein (moyenne des années 2021-2035, selon le modèle et le scénario). Il augmente avec le niveau d'ambition de l'objectif en matière d'électricité renouvelable dans les scénarios, car davantage de nouvelles centrales photovoltaïques et autres centrales électriques sont mises en chantier. Au fil du temps, l'augmentation des capacités entraîne également une hausse de l'emploi dans l'exploitation et la maintenance des centrales existantes. L'emploi par unité de capacité supplémentaire diminuera en raison de la baisse des coûts d'investissement des centrales photovoltaïques et de l'augmentation de la productivité du travail. En revanche, l'emploi dans les centrales nucléaires diminue en raison de leur abandon progressif. Cependant, la baisse de cet 'emploi est retardée au-delà de 2035 en raison de la longue période de post-exploitation et de démantèlement, qui maintient l'emploi pendant plus d'une décennie après la fermeture d'une centrale nucléaire. En raison de la forte expansion des capacités, la plupart des emplois créés sont liés à la construction de nouvelles installations. L'emploi dans l'exploitation des centrales électriques et chez les fournisseurs de services d'exploitation et de

maintenance est moins important, mais reste néanmoins substantiel. Les emplois dans l'approvisionnement en combustible (sylviculture et approvisionnement en gaz) sont nettement moins nombreux. Les emplois dans le démantèlement des centrales nucléaires sont importants, représentant près de 2 000 emplois en 2035.

Au niveau régional, nous présentons les résultats pour les cantons et les trois régions EDGE (villes, Plateau, Alpes). Les effets sur l'emploi régional dépendent de la mesure dans laquelle les régions abritent des centrales électriques et participent aux chaînes d'approvisionnement induites par la construction, l'exploitation et le démantèlement des centrales électriques. L'importance relative de l'emploi au niveau régional dépend également de la taille des économies régionales. Les effets sur l'emploi régional varient fortement selon les modèles et les scénarios. L'emploi augmente généralement avec le niveau d'ambition des scénarios, mais la répartition régionale diffère entre les modèles. Elle tend à être plus élevée pour le modèle Nexus-e que pour les modèles EXPANSE et OREES, car l'augmentation de la capacité tend à être plus importante. Elle tend également à être répartie de manière plus uniforme entre les cantons, car Nexus-e concentre moins les installations sur les sites les plus productifs. Les résultats au niveau cantonal montrent que la part de l'emploi induit par la production d'électricité dans l'emploi total est plus élevée pour les cantons des Alpes (Glaris, Grisons, Uri et Valais), qui profitent de la présence d'énergies renouvelables, et pour les cantons qui accueillent des centrales nucléaires. Il est également évident qu'à long terme, après la fin de la période de démantèlement, l'emploi dans les cantons d'Argovie et de Soleure, lié aux centrales électriques et à leurs chaînes d'approvisionnement, diminuera en raison de la transition énergétique. Dans la plupart des autres cantons, il augmentera, de sorte que l'emploi dans ce petit segment du secteur énergétique sera réparti plus uniformément entre les cantons.

Pour les régions EDGE, nos résultats montrent que la plupart des emplois liés à la production d'électricité seront créés dans les villes, mais que la part de ces emplois dans l'emploi régional total sera plus élevée pour les Alpes et les régions de moyenne altitude.

Nos résultats ne reflètent que la période comprise entre 2021 et 2035, car les résultats des modèles énergétiques se réfèrent à 2035. Ils ne fournissent donc qu'une partie des impacts de la transition énergétique sur l'emploi, qui se poursuivra fortement après 2035. Notre période de référence se caractérise par une forte augmentation des capacités de production d'énergie renouvelable, qui induit principalement des emplois dans la construction de nouvelles installations électriques et donc des emplois temporaires qui diminueront lorsque la période de forte augmentation des capacités sera terminée et lorsque les centrales électriques existantes seront remplacées. Dans le secteur de l'électricité, la transition énergétique se caractérise également par un transfert des emplois dans l'exploitation des centrales électriques vers des emplois dans la construction de nouvelles installations et chez les fournisseurs des centrales électriques.

L'approche méthodologique que nous avons utilisée est flexible dans la mesure où elle peut inclure les informations disponibles sur les chaînes d'approvisionnement spécifiques à chaque technologie et s'adapter à différentes situations en matière de disponibilité des données. Lorsque des chiffres spécifiques à l'emploi sont disponibles pour des technologies particulières, ils peuvent être intégrés. Nous avons par exemple inclus des facteurs d'emploi pour les centrales nucléaires et l'approvisionnement en combustible, sur la base des rapports des entreprises et des statistiques officielles. Cette approche permet de couvrir de manière exhaustive l'ensemble du cycle de vie des centrales électriques, de la construction au démantèlement, ainsi que les activités des chaînes d'approvisionnement respectives. En ce qui concerne les estimations de l'emploi régional, l'approche utilise les informations sur l'emplacement des installations électriques. Une part importante de l'emploi régional peut être déduite de ces informations et des caractéristiques des activités économiques induites. Pour le segment des fournisseurs directs de la construction, de l'exploitation et de la maintenance et du démantèlement des centrales électriques, une certaine incertitude subsiste. Dans ce cas, une enquête auprès des entreprises actives dans le domaine de l'énergie et leur répartition régionale permettrait d'améliorer la précision des résultats. Une telle enquête n'a pas été possible dans le cadre de ce projet.

Nos résultats ne concernent qu'un petit segment de la transition énergétique, à savoir l'offre en matière de production d'électricité. La production de chaleur, la mobilité et les changements du côté de la demande n'ont pas encore été pris en compte. L'approche méthodologique appliquée dans le présent rapport peut généralement être appliquée à d'autres aspects de la transition énergétique afin d'estimer leurs conséquences sur l'emploi.

1 Introduction

The transition towards a fully renewable energy system in Switzerland will have broad socio-economic implications. Apart from the overall economic impacts, SWEET EDGE aims at analysing the distributional impacts of the energy transition, including differences among regions in Switzerland.

The deployment of energy technologies induces a large variety of economic activities spanning across industries and country borders. Technology specific supply chains are organised around the life-cycle phases of energy facilities, that comprise construction, “operation and maintenance” (use phase) and dismantling after the end of the use phase. They include highly specialised activities that may be concentrated in certain world regions (e.g. solar cell manufacturing in China) as well as common activities that occur in the regions of the plant sites (e.g. plant operation, construction or planning). An assessment of the regional employment impacts of energy strategies therefore needs to take the technology specific supply chains into account adequately.

The remainder of this report is structured as follows. In the rest of this chapter we formulate our research questions, perform a brief literature review of employment impact assessment studies and give an overview on the results of the energy models that are the basis for our estimates on employment impacts. In chapter 2 we present our methodological approach and the data used in our assessment. Chapter 3 contains the results on national and regional employment impacts. These are followed by a discussion and concluding remarks in chapter 4.

1.1 Research objective

Within the EDGE project, Heinisch et al. (2023) have analysed scenarios with high shares of renewable electricity generation in Switzerland with different energy system models. The aim of this report is to estimate the national and regional employment impacts of these scenarios as a contribution to the analysis of the distributional impacts of the energy transition. It aims at answering the following research questions:

- What is the impact of the transition to renewable electricity generation on regional labour markets? How are the impacts distributed across regions and industries?
- What is the impact on a national scale (focusing on the electricity generation system and supply chains)?
- How well can the regional labour markets accommodate the changes that are induced by the energy transition?

1.2 Literature review of employment impact assessments

In the last two decades, a variety of studies (both in peer-reviewed journals and in grey literature) has analysed employment impacts of renewable energy technology deployment (RETD). They mainly differ regarding research objectives, system boundaries and methodological approaches (see Breitschopf et al. 2013, Jenniches 2018 and Hanna et al. 2024 for reviews of employment assessment studies).

With regard to **research objectives**, we can roughly distinguish studies analysing (gross) labour requirements and those analysing (net) employment impacts of the transition from non-renewable to renewable energy technologies. Since this transition is associated with the emergence of new technologies, economic activities and supply chains, that are presently not well represented in official statistics, there is an interest in the number of jobs that can be generated or are sustained by RETD. Other research questions refer to the distribution of jobs across industries and regions and the match between necessary and available labour skills and skill levels. Studies termed as value chain gap analysis have analysed value chains associated with RETD, the national or regional ability to cover the different segments of the value chains, existing gaps and options to address the gaps.

Some studies have compared the labour requirements between renewable energy technologies and conventional energy technologies that would be replaced by the former. They have partly also addressed the job distribution across regions, industries, skills and gender.

Net employment impact studies are interested in the overall impact of the energy transition on employment. While (gross) labour requirement studies are often scenario based and only address energy supply, net employment impact studies often analyse the impact of transition policies such as carbon taxes and also address energy demand.

These types of studies also differ with regard to the economic **impact mechanisms** that they take into account. Following and extending Breitschopf et al. (2013), the following generic impact mechanisms can be distinguished:

- **Direct impacts** of investment in construction of new plants and infrastructures, operation and maintenance (O&M) of and fuel supply for existing

plants on economic activities. In the energy transition context, the impacts typically are positive for RE and negative for CE plants, compared to a reference scenario without RETD.

- **Indirect impacts** on economic activities that are triggered in the supply chains of directly affected economic activities through the demand for intermediate inputs or investment goods. These impacts can also be positive or negative.
- **Induced impacts:** changing employment in the directly and indirectly affected industries may change labour income of households and thus their consumption expenditures. This affects the economic activities supplying consumer goods and services.
- **Impacts of price, income and budget changes**: the shift from conventional to renewable energy technologies can lead to changing energy prices and thus to price changes along supply chains and various reactions of enterprises and households to these changes due to limited budgets, e.g. changing investment or consumption decisions. The energy transition can affect government income via taxes or subsidies and changes in government budgets and expenditures can result with subsequent economic impacts.
- **Supply side impacts**: if supply side factors are nationally or regionally limited (e.g. supply of labour with the required skills), additional demand can lead to crowding out of other expenditures and economic activities.
- **Wider economic impacts** such as third-round effects, trade impacts etc.

While the direct and indirect impacts are closely related to the technological and structural change induced by the energy transition, the latter impacts belong to the economy-wide or general equilibrium impacts. The following table displays to what extent the different impact mechanisms are included by the different types of employment studies. While gross labour requirement studies focus on the direct, indirect and partly induced positive impacts of RETD and on the structural characteristics of labour requirements, comparison studies also take the negative impacts of reduced deployment of conventional energy technologies into account. This can be especially important for regional employment studies, since the regional distribution of employment can differ strongly between CET and RET. Studies interested in the overall net employment impacts of RETD or RET promotion policies usually take all impact mechanisms into account.

Impact mechanism	**(Gross) labour requirement studies**	**Comparison of labour requirements**	**(Net) employment impact studies**
Additional construction, operation and dismantling of RE plants (direct and indirect)	x	x	x
Less construction, operation and dismantling of CE plants (direct and indirect)		x	x
Impacts of price, income and budget changes	(x)	(x)	x
Supply side impacts (crowding out)			x
Further economy-wide impacts			x

Table 1: Types of employment studies and impact mechanisms considered

Regarding **time**, we can distinguish ex-post studies that analyse the past or present employment impacts and ex-ante studies that estimate potential employment impacts in the future based on scenarios.

Regarding **system boundaries**, firstly the spatial system is relevant. Employment impact studies have been done for the national, regional and international level. Secondly, the boundary of the analysed system is a distinctive feature. Gross labour requirement studies often focus on the energy sector and (partly) its supply chain, while net employment impact studies usually take the whole economy into account.

With regard to the **methodological approaches** applied, we can distinguish between

- the employment factor approach,
- supply or value chain analysis,
- input-output (IO) modelling and
- economy-wide modelling with econometric IO or CGE models.

The **employment factor approach** estimates the labour requirement associated with RETD by multiplying installed capacities, annual capacity installation or dismantling or electricity generation in physical units (e.g. in MW or GWh) with technology specific employment factors per unit of installed capacities, annual capacity installation or dismantling (e.g. in fulltime equivalents FTE or FTE years per

MW). Employment factors have been generated from different sources such as dedicated labour requirement assessments (e.g. Singh/Fehrs 2001), company surveys (e.g. Briggs et al. 2020) and data from industry associations or case studies. Employment factors have often been transferred from the original region to other regions, partly by using time-related or region-specific correction factors (Ram et al. 2022). The accuracy of the factors depends strongly on the adequacy of these sources and the accuracy of the methods for calculating the factors. The employment factor approach has mainly been used in employment requirement studies of RETD (Ortega et al. 2015), the comparison of RET and CET (Sharma/Banerjee 2021) or analyses of the whole energy sector (Ram et al. 2022). The estimation of net employment impacts is not possible with this approach.

Supply chain analysis determines the economic activities in the supply chains associated with RETD (e.g. DTI 2004) and collects data on the level of activities that are present in a certain country or region (e.g. turnover or employment). Often primary data are collected through company surveys or interviews and combined with available statistics. Supply chain analysis is sometimes combined with gap analysis to analyse the gaps between required and available skills and competences and options for improved supply chain coverage and thus additional economic potential (Putsche et al. 2024, Lobsiger, Rutzer 2021). The number of supply chain analyses is quite limited due to the necessity of collecting primary data. This method is mainly useful for gross labour requirement studies of RET.

The **input-output modelling approach** is widely used to estimate the economic and employment impacts of RETD (Breitschopf et al. 2013; Nathani et al. 2013 and Nathani et al. 2022 with applications for Switzerland). It combines the analysis of expenditures associated with investments in new plants, O&M of existing plants and dismantling of plants at the end of their lifetimes with input-output modelling. Expenditures are either taken from existing data (e.g. company data) or estimated by multiplying capacity data with technology specific investment, O&M and dismantling costs. The expenditures are then allocated to cost components (e.g. planning, installation on-site, PV modules or inverters) and to the economic activities that produce and supply the components. The activity data (usually in the form of the output value) are then linked to an input-output model of the respective country extended with data on industry specific labour volume to estimate the direct and indirect employment required in the energy sector and its supply chains. This method requires technology specific data on capacities, specific costs, cost structures and economic activities involved in the supply chains. In some cases, a form of supply chain analysis is used to generate the necessary data (Lehr et al. 2008). The approach assumes that the industries represented in the input-output model are representative for the economic activities present in the supply chains of RETD with regard to intermediate input structures and employment intensity. Classic input-output modelling is mainly used in gross employment requirement studies (Cai et al. 2017), partly only covering RET and partly covering both RET and CET. Induced, price, income and budget related impacts can be included with exogenous assumptions on price propagation, price and income elasticities or the handling of budgetary changes (see Többen 2017 for a combination of quantity and price IO models), but the coverage of economy-wide impact mechanisms is limited. For this, more sophisticated input-output models are needed (see below).

Economy-wide modelling aims at modelling the overall economy-wide impacts of RETD or policies promoting RETD. Basically, two types of models have been used: CGE models (e.g. Allan et al. 2008, Gilmartin/Allan 2015) and econometric input-output models (e.g. Lehr et al. 2012).

Regional employment impact assessment approaches

In principle, regional employment impact assessment studies apply the same methodological approaches as studies targeting the national level. An additional challenge lies in allocating the impacts to the sub-national regions, since sub-national statistics are generally less comprehensive. In some studies using the employment factor approach, the scope of employment impacts is restricted to activities that are assumed to be available locally (e.g. operation of plants and planning, engineering and construction of new plants in Sharma/Banerjee 2021). The regional distribution of employment is then linked to the regional distribution of the location of energy plants / facilities. Sastresa et al. (2010) performed a kind of a supply chain analysis of companies in the RE supply chain for the Spanish region of Aragon without using this methodological term. The results were also used to calculate regional employment factors. Heinbach et al. (2014) aim to estimate value added and employment generated at the municipality level with a value chain analysis of RE technologies in Germany. Expenditures for constructing new plants, O&M and dismantling of plants are estimated from capacity and cost data. The expenditures are then broken down to detailed value chain steps. After accounting for imports and exports, the local contribution to the respective economic activities is analysed and an income approach is used to calculate local net value added and employment. Input-output modelling has been used in different

variations for the assessment or regional employment impacts. Többen (2017) uses a multiregional input-output model for Germany to take supply chain impacts across regional boundaries into account. Ulrich et al. (2012) use a national IO model for estimating employment impact of renewable energy expansion at the state level in Germany. They distinguish regional direct and indirect production and employment. Regional direct production and employment is determined based on the plant locations and a survey of companies active in the regional energy field that also identifies their location. Regional indirect production is estimated with a regional reallocation model that includes a gravity approach estimating cross-regional deliveries as a function of distance between states. This approach was used as a regional add-on to the modelling of national employment impacts with an econometric IO model. Regarding other economy-wide approaches, Allan et al. (2008) and Gilmartin/Allan (2015) are examples of regional CGE models. This approach is probably only feasible for large subnational regions with extensive national accounting data available.

Comparison of strengths and limitations

The methods introduced above have their specific strengths and limitations. The employment factor approach works with capacity data that are easily measurable. The accuracy of this approach depends on the accuracy of the employment factors that need to adequately take the national and regional specificities into account. Using employment factors from other countries and time periods can be associated with uncertainties. This approach appears to be especially applicable for easily identifiable activities such as operation of power plants, construction and installation or planning. It seems less suitable for activities that are less tractable or part of complex supply chains and for activities in higher tiers of supply chains, unless significant resources are invested in collecting the necessary data. The supply chain analysis approach seems better able to tackle the complexities of supply chains, but also needs significant resources for data collection to deliver accurate results. Input-output modelling has the advantage of taking into account all economic impulses that are associated with RETD and being able to fully track the relevant supply chains. Its main disadvantage is the assumption that industry averages for employment intensities and supply chain transactions are adequate representations of the technology specific employment intensities and supply chains in the absence of specific data. Economy-wide modelling is able to take economic impact mechanisms fully into account, but their use is only possible if the respective models are readily available. It is too resource-intensive to set them up just for employment impact assessment. For regional impact assessment the availability of regional models is required that is seldom the case.

In this report we use the input-output modelling approach since it allows to comprehensively and coherently build on the results of the energy models. Other advantages are its comprehensive coverage of supply chains in the economy while offering a good level of industry detail. We combine the approach with elements of the employment factor approach and supply chain analysis when better data are available. The methodological approach and the data used are described in detail in chapter 2.

1.3 Summary of the results of the energy models

Our starting point are the results of the energy system models in the task 1 of work package 7. In the first modelling intercomparison of the SWEET EDGE project, scenarios with high shares of renewable electricity generation in Switzerland were simulated with three technology-rich, spatially and temporally differentiated energy system models, EXPANSE, Nexus-e and OREES (Heinisch et al. 2023). Three base scenarios were considered for the year 2035:

- “RES” with a target of 17 TWh annual electricity generation from new renewable sources (solar photovoltaic (PV), wind and biomass)
- “HighRES” with a higher target of 25 TWh annual electricity generation from new renewable sources,
- “High Solar” with a PV specific target of 25 TWh annual electricity generation from PV units.
- The “VeryHighRES” with the highest target of 35 TWh annual electricity generation from renewable sources was later added by the modelling teams as a fourth scenario.

The three models shared common assumptions on electricity demand and on a full nuclear phase-out by 2035. The use of hydro power plants was kept constant in the EXPANSE and the OREES model and was assumed to grow moderately in the Nexus-e model. The basic scenarios were combined with high and low assumptions on electricity demand (scenario variants named DemHigh and DemLow), on levels of battery storage installations (named BatHigh and BatLow) and with the assumption of complete independence from fossil fuels for domestic electricity generation (No Fossil). The VeryHighRES scenario was only combined with the DemHigh and DemLow variants. In total, 21 scenarios were modelled with each model.

These scenarios thus depict a shift from large, centralised electricity generation plants, mainly nuclear power plants, but also a few large gas-fired combined cycle power plants, to decentralised,

smaller units based on renewable energy sources such as wind, biomass and solar PV power plants down to small roof-top PV installations.

Figure 1 contains an overview of the results for the three main scenarios. All three models project a strong increase of PV capacities and PV-based electricity generation until 2035. The higher RES targets in the High RES and the High Solar scenarios are also mainly achieved with additional PV deployment. The contribution of other new renewable technologies remains limited and the use of hydro power does not change between the scenarios. The model results differ with regard to the contribution of biomass, wind and gas power plants. They also differ regarding net electricity imports. In the RES scenario net imports are substantial in all model results. They are reduced in the High RES and the High Solar scenario by increasing generation from new renewables. Turning to the results for electricity generation capacity, all models project a strong increase in PV capacities until 2035 with the other new renewable technologies remaining marginal. The OREES model projects lower PV capacities, since it optimises for locations with higher capacity factors. Hydro power capacities do not differ between the scenarios. The results for storage capacity show that pumped hydro storage plants remain the most important storage technology. Only the Nexus-e model projects a minor role for batteries. In all model results for all scenarios grid expansion is negligible (EXPANSE) or not accounted for (Nexus-e and OREES).

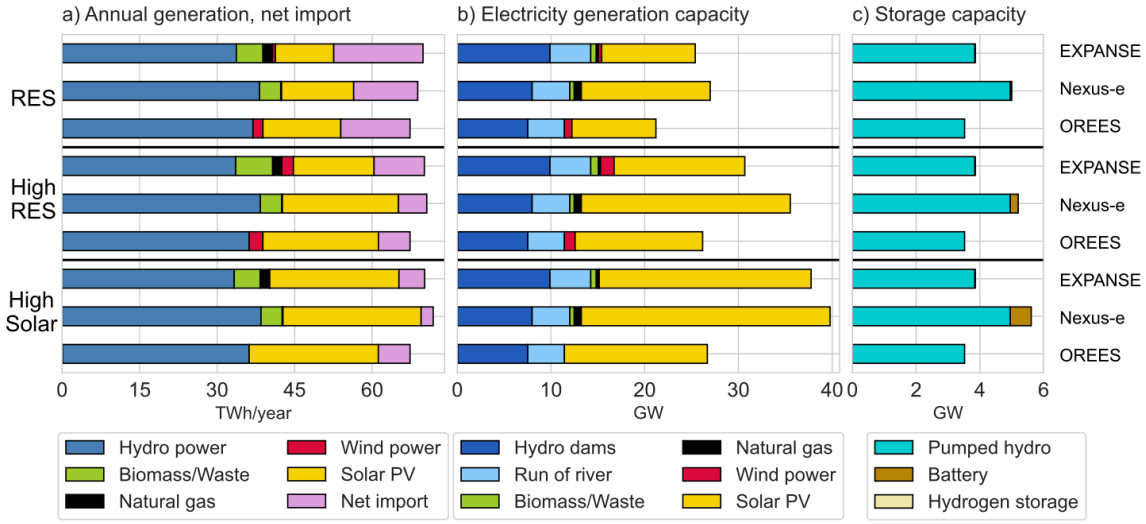


Figure 1: Overview of energy system model results for the main scenarios (Heinisch et al., 2023)

The results for the scenario variants show minor deviations from the results for the main scenarios. Variation in electricity demand is mainly met by variation in electricity imports, to a minor extent also by changing PV- or wind-based generation (see appendix to Heinisch et al., 2023). The “No Fossil” scenarios mainly result in higher imports and to a minor degree in higher PV- and wind-based generation. The results for scenarios with higher or lower battery availability only show minor deviations from the base scenario results.

2 Methodological approach and data

The estimation of the employment impacts of the energy transition builds upon the results of the energy system models. Their outputs describe for each scenario the electricity system in the year 2035.

The model results include for each scenario the following variables:

- the installed electricity generation and storage capacities in the year 2035 by technology and canton (all models) or municipality (EXPANSE and OREES),
- annual electricity generation in the year 2035 by technology and canton (all models) or municipality (EXPANSE and OREES),
- annual electricity imports to Switzerland and exports from Switzerland,
- grid expansion within Switzerland and to the neighbouring countries,
- total investment and running costs of the electricity system.

The development of the electricity sector can have first-round or direct effects on the following economic activities:

- Operation and maintenance (O&M) of power plants and storage facilities (pumped hydro power plants or batteries),
- construction of new power plants and storage facilities and/or replacement of (parts of) existing power plants and facilities,
- dismantling of power plants that have reached their end-of-life,
- expansion of the electricity grid,
- imports and exports of electricity.

These economic activities require a variety of goods and services and thus induce further economic activities in their respective supply chains. These are called indirect or second-round effects. Finally differences in electricity costs and prices can lead to additional economic impacts.

In this study, we focus on direct and indirect employment impacts in the electricity generating industry and its supply chains. Other activities in the electricity supply industry such as operation of grids and electricity distribution and trade are not considered. Additional economy-wide impacts are not considered. Since the EDGE scenarios do not include a reference scenario, we report absolute employment numbers in fulltime equivalents, from which differences between the scenarios can be derived. The employment impacts are displayed for the period between the base year 2020 and the year 2035 to account for the dynamics in the development of the electricity system. They are analysed for the national level as well as for cantons and regions based on types of municipalities (see below).

In the following, we first give a brief introduction into input-output analysis in general and then describe the applied method in detail.

2.1 A brief introduction into input-output analysis

Input-output tables are the empirical basis of input-output modelling (Miller/Blair 2009). They capture the flows of goods and services between the industries of the economy and from the industries to the sectors of final demand (household consumption, consumption of non-profit institutions serving households (NPISH), government consumption, gross fixed capital formation and exports). Every industry is quantitatively represented by its inputs (columns of the IOT) and its outputs (rows of the IOT). The inputs include intermediate inputs from the own industry and other industries as well as value added components such as labour compensation, capital depreciation and profits (also called primary inputs). The outputs include outputs to its own industry, other industries and the final demand sectors. For every industry the row sum equals the column sum. An IOT consists of three quadrants or matrices: the intermediate input matrix, the value-added matrix and the final demand matrix. For employment analysis the IO table is extended with industry specific employment data.

Input-output tables differ regarding the way imports are recorded. In the Swiss IOT, the rows include domestic and imported products. The row sums therefore represent total use of domestic and imported products. To balance this, a row of imports by product group is included in the IOT, so that the row sums represent total supply of products that equal total use.

Based on this empirical basis, a modified version of the original static open Leontief model states that product supply can be calculated from final demand with the following formula

$$S = (I - A)^{-1} Y$$

With S: vector of total product supply
Y: vector of final demand
A: intermediate input matrix
I: identity matrix

Domestic output X is given by

$$X = S(1 - \widehat{MS^{-1}})$$

with M: import vector

Domestic employment induced by final demand E can be calculated as

$$E = \widehat{FX^{-1}}X$$

With F: vector of employment by industry.

2.2 Methodology

The developments in the electricity system, that are analysed in the EDGE scenarios, affect the following elements of the input-output table:

- Expenditures for investment in electricity generation capacities, storage capacities and grid expansion as well as expenditures for the dismantling of electricity generation and storage capacities are recorded as part of final demand – belonging to gross fixed capital formation.
- Generation of electricity is recorded as rows and columns of the input-output table. In the columns the intermediate inputs from other industries and the value-added components are recorded. In the rows the supply of electricity to the electricity distribution and trade industry is the only entry.

- Imports and exports of electricity are recorded as imports and exports of the electricity distribution and trade industry.

One modelling option would be
- to forecast the energy IOT to the year 2035 and to adapt the respective elements of the IOT to reflect the scenario outcomes (as in Füllemann et al. 2020),
- to calculate for each scenario the employment impact of final demand. The difference of employment results between scenarios then reflects the difference in policies. One scenario would have to be determined as the reference scenario.

In an alternative modelling option, that we use in this report, the elements of the IOT that are affected by the scenarios, are exogenised. The main advantage of this approach is that the determinants of the employment impacts can be better identified and separated. It is thus possible to distinguish between the employment impacts of construction, O&M and dismantling of power plants.

This calculation approach consists of the following major steps:
- Calculate the investment, O&M and dismantling expenditures by year and technology and break them down to cost components and subsequently to economic activities of the industry classification used in the IO model;
- Exclude the electricity generation activities (rows and columns) from the IOT to avoid double counting;
- Determine employment in operation of power plants from labour costs and assumed labour income per FTE;
- Calculate total product supply (domestic and imports) by industry with the IO model;
- Determine direct and indirect domestic employment in the electricity sector and supply chains by industry from domestic output with industry specific employment factors.

This calculation is done with a spatial resolution to be able to account for regional employment impacts. We first analyse impacts by canton and additionally by type of municipality. The municipalities are aggregated to nine regions that result as a combination of the type of municipality (urban, periurban or rural) with the type of mountain region (alps, jura or midlands). Each Swiss municipality is assigned to a type based on spatial classifications from the Swiss Federal Statistical Office. The nine regions are further aggregated to three regions that are used in the EDGE project and defined as follows:
- The “cities” region comprises all municipalities that are classified as “urban” in the typology of municipalities 2012;
- the “Alps” region comprises all municipalities that are not classified as “urban” and that are located in the Alps according to the typology of European mountain regions;
- the "midlands" region comprises all the other municipalities.

The estimation of the regional distribution of employment impacts comes with large uncertainties, especially with regard to a future year. Our starting point for estimating regional employment is the information given by the energy system models on the plant site region of standing capacities and annual capacity installed. Economic activities that are induced by investment in, operation and maintenance and finally dismantling of plants are tied in different degrees to the location of the plant sites. We can distinguish between employment in power plants, direct employment in companies supplying goods and services for investment, O&M and dismantling of power plants, and indirect employment in second and higher tier supplying companies. Employment in power plants is by definition allocated to the region the plant is located in. For direct employment in supplying firms, we can assume the regional employment shares to depend on the specific supply chains characteristic for the electricity generation technologies, the nature of the economic activities present in the supply chains and the match between the required skills and skills available in the plant site regions. Highly specialised activities will be located in the regions of the respective manufacturers, which are generally unknown and may also be influenced by chance. For the indirect impacts in second and higher tiers of the supply chains, we can assume the share of technology specific activities to be lower and that of more general activities to be higher than for the direct impacts. Thus, it is probable that the regional distribution of these activities resembles that of the respective industries. To make an example: PV installations are widely distributed across Switzerland. We can therefore assume general activities such as planning and installation to be covered by companies in the region of the PV plants. The supply of specific plant components such as PV modules, inverters or mounting systems is covered by specialised companies, whose locations are independent of the plant site regions. These companies need more general inputs such as aluminium profiles, nuts and bolts, electrical components, that can come from domestic or foreign companies. For these second and higher tier companies, we apply industry specific import shares and the regional distribution of the respective industries.

The main uncertainty associated with this regionalisation approach probably lies with the estimation of regional shares for direct employment in supplying companies. The regional allocation of

employment in power plants is straightforward. The regional allocation of indirect employment (second and higher tiers) suffers from missing information on the one hand, but also could be quite realistic on the other hand, since the higher upstream tiers of the supply chain will probably consist of more general activities that are less specific to the RETD supply chains and to the plant locations than the direct suppliers. For the regional allocation of the latter, a dedicated analysis or survey of the locations of supplying companies would be beneficial, but this was not possible in the context of this project. The distribution of employment according to the shares in the STATENT statistics probably overestimates the number of participating regions due to the strong specialisation of companies.

As mentioned in chapter 1.2, one regional approach in the literature includes a gravity approach (Ulrich et al. 2012) that uses the distance between the receiving and the supplying region as a determinant of regional allocation. This approach may be applicable to a country like Germany that is eight to nine times larger than Switzerland. In our view, distance probably is a less important determinant in Switzerland than in Germany. We therefore did not apply the gravity approach in this study.

This modelling approach is explained in detail in the following.

Given

- $t = 2021 \ldots 2035$ as the years of the analysed time period
- $g = 1 \ldots G$ as electricity generation technologies with lifetime n_g
- $i,j = 1 \ldots I$ as industries of the Swiss energy IOT
- $k,m = 1 \ldots K$ cantons of Switzerland
- $r,q = 1 \ldots R$ as EDGE regions of Switzerland
- s as scenario
- $scap_{s,g,k,t}$ as the standing capacity (i.e. the total capacity installed) in MW of technology g in scenario s, canton k of the plant site at the end of year t. The standing capacity of technology g in canton k is given as a result of the energy system models for the beginning of a model specific base year and the end of the year 2035. For the intermediate years we assume a linear development of installed capacities.

Annual capacity installed (ACI) generally consists of capacity addition (difference of installed capacities between two years) and replacement of capacities that have reached the end of their lifetime. Capacity replacement in year t is equal to the sum of capacities installed in past years that have reached the end of their lifetime. ACI can be calculated as follows:

$$aci_{s,g,k,t} = icap_{s,g,k,t} - icap_{s,g,k,t-1} + \sum_{q=1}^{\infty} aci_{s,g,k,t-qn_g}$$

with q_n denoting multiples of the technology lifetime n.

We analysed the power plant vintages in Switzerland and found that capacity addition clearly dominates capacity replacement for new renewable energy technologies until 2035. We therefore neglect capacity replacement in the calculation of annual capacity installed. Hydro power plants need to be treated differently from new renewable energy technologies, since these are complex systems that include components with varying lifetimes between 30 and 80 years and furthermore, they are highly site specific. We therefore estimate expenditures for capacity replacement in hydro power plants separately as described below.

Our analysis of power plant vintages also shows that dismantling of nuclear power plants dominates in the time period until 2035 under the assumption of a nuclear phase-out. Dismantling of other technologies is negligible. The time schedule of dismantling of nuclear power plants is directly taken from the literature (see below). The capacity under dismantling for technology g in the plant site canton k in year t thus is

$$dcap_{g,k,t} = \begin{cases} dcap_{nuc,k,t} \; if \; k = nuclear \\ 0 \; otherwise \end{cases}$$

Based on the capacity data and data on specific costs, investment, O&M and decommissioning expenditures are calculated as follows:

Investment expenditures

$$invexp_{s,g,k,t} = aci_{s,g,k,t} \; sic_{g,t}$$

with $sic_{g,t}$ as specific investment costs per unit of annual capacity installed

O&M expenditures

$$omexp_{s,g,k,t} = icap_{s,g,k,t} \; soc_{g,t}$$

with $soc_{g,t}$ as specific O&M costs per unit of installed capacity.

Regarding nuclear power plants, investment expenditures mainly reflect investment in replacement of worn-out components and in improving plant security. We estimate average annual investment with ratios of investment expenditures per unit of installed capacity based on annual reports of two nuclear power plants (see

below). Regarding hydro power plants, average replacement investments are estimated with ratios per unit of installed capacity taken from Piot (2018). Annual dismantling expenditures for nuclear power plants $disexp_{nuc,k,t}$ are estimated from the literature (see below).

In the next step, investment, O&M and dismantling expenditures are broken down to cost components and to supplying industries with data on technology specific cost structures. The breakdown by cost components is usually taken from the techno-economic literature. For instance, expenditures for the construction of new PV plants are typically distributed to the following cost components (Bloch/Sauter 2024):

- planning of the PV plant,
- installation work,
- PV modules,
- inverters,
- the mounting system,
- electrical equipment and
- other costs.

The purchase of PV modules can then be further allocated to economic activities, e.g. wholesale, transport and manufacturing of the PV modules. Usually, the breakdown of expenditures to cost components is available from the techno-economic literature or expert judgement. The allocation to economic activities often is a second step that is required to make the techno-economic data compatible with concepts of national accounting that are used in IO modelling.

We distinguish between labour costs, other value added and expenditures for goods and services from other companies. Labour costs are used to calculate direct employment in the operation of plants by assuming average wages. Other value added is not relevant for employment and expenditures for goods and services are subsequently used to estimate direct and indirect employment with the IO model.

$$labcost^{O\&M}_{s,g,k,t} = omexp_{s,g,k,t}\ labshr^{O\&M}_{g,t}$$

with $labshr_{g,t}$ as the share of labour costs in O&M expenditures

$$labcost^{Dism}_{s,nuc,k,t} = disexp_{s,nuc,k,t}\ labshr^{Dism}_{nuc,t}$$

with $labshr_{nuc,t}$ as the share of labour costs in expenditures for dismantling of nuclear power plants

Direct employment for the operation or dismantling of power plants is derived as

$$emp_op^{O\&M}_{s,g,k,t} = labcost^{O\&M}_{s,g,k,t} \,/\, wage^{O\&M}_{g,t}$$

for operation of plants and

$$emp_op^{Dism}_{s,nuc,k,t} = labcost^{\mathrm{Dism}}_{s,nuc,k,t} \,/\, wage^{Dism}_{nuc,t}$$ for dismantling of plants

with $wage^{O\&M}_{g,t}$ as wage per FTE in O&M of power plants and $wage^{Dism}_{nuc,t}$ as wage per FTE in dismantling of nuclear power plants.

An exception is employment in nuclear power plants, which is directly taken from annual reports and other company data. Employment is kept constant until the phase-out of each nuclear power plant. Based on BKW (2023) we assume that the employment level remains unchanged in the post-operation period for a given number of years.

After the breakdown of expenditures for the purchase of goods and services by industry these result as

- investment expenditures by supplying industry $invexp_{s,g,k,t,c,i}$
- O&M expenditures by supplying industry $omexp_{s,g,k,t,c,i}$ and
- dismantling expenditures by supplying industry $disexp_{nuc,k,t,c,i}$

Using $p \in (invexp, omexp, disexp)$ for the type of expenditure and c for the cost components, expenditures are characterised by the scenario, technology, site canton, year, type of expenditure, cost component and industry.

$$exp_{s,g,k,t,p,c,i}$$

For the estimation of employment impacts, it is often critical to take imports adequately into account. If available, we use information on import shares at the component level (e.g. for manufacturing of PV modules). If no specific data are available, we use industry specific average import shares from the IOT. Imports are deducted from expenditures to yield domestic output:

$$output_{s,g,k,t,p,c,i} = exp_{s,g,k,t,p,c,i}\ impshr_{g,p,c,i}$$

Direct employment is then calculated by multiplying domestic output with labour intensity (number of FTE per unit of domestic output), taken from the IOT. Labour intensity $labint$ is industry and time specific to reflect sectoral labour productivity differences and productivity development.

$$emp^{dir}_{s,g,k,t,p,c,i} = output_{s,g,k,t,p,c,i}\ labint_{t,i}$$

After aggregating across cost components and collecting all domestic output per scenario and year into one matrix $O_{s,t}$ with the expenditure types, technologies and regions as columns and the industries as rows, we derive intermediate

consumption from domestic output with the input coefficient matrix A from the IOT:

$$C_{s,t} = A\, O_{s,t}$$

To calculate indirect employment, we treat intermediate consumption induced by electricity generation as exogenous final demand and use the extended input output model to calculate employment in all industries of the economy.

$$E_{s,t}^{ind} = \widehat{F_t X_t^{-1}}\, \widehat{M_t S_t^{-1}}\, (I - A_t)^{-1}\, C_{s,t}$$

Total employment by scenario and year is then given as the sum of employment for the operation of power plants, other direct employment and indirect employment.

$$E_{s,t} = E_{s,t}^{op} + E_{s,t}^{dir} + E_{s,t}^{ind}$$

with $E_{s,t}^{dir}$ consisting of the $emp_{s,g,k,t,p,c,i}^{dir}$ elements

The employment induced by operation and maintenance of power plants are permanent jobs indicated in FTE, while the employment induced by investment in and dismantling of power plants are temporary jobs, indicated in FTE years.

For indirect employment in supply chains calculated with the IO model, we assume an industry specific cantonal distribution proportional to the STATENT data in 2021.

Our starting point for estimating regional employment is the information given by the energy system models on the plant site region of standing capacities and annual capacity installed. Employment in power plants is by definition allocated to the region the plant is located in. For direct employment in supplying companies, we estimate a share of employed persons that work in the canton of the plant site. The rest of direct employment (located outside the plant site canton) is assumed to be independent of the plant site canton. It is aggregated across cantons and then redistributed to the cantons according to the employment shares of industries in the official statistics STATENT. This statistic contains data on employment in fulltime equivalents by canton and industry.

Following are some examples for the reasoning behind the assumptions of regional employment shares.

- Employment for planning and construction and most installation activities is fully allocated to the canton of the plant site. For wind power plants, we assume the on-site-construction to be done by the wind turbine manufacturers located abroad (based on expert information) and the connection to the grid to be done by cantonal companies.
- Employment for manufacturing and other activities that do not have a link to the site of power plants get a cantonal share of 0%. Here we assume that manufacturing takes place in the canton where the manufacturer is located. For manufacturers that compete on global markets we need to take into account that these are often highly specialised and that a large share of their products are exported. On the other hand, the products of their foreign competitors are imported into the Swiss market. For instance, in 2022 more than 96% of PV modules installed in Switzerland were imported. On the other hand, 72% of PV modules produced in Switzerland were exported (SFOE, 2024b).

Indirect employment by industry is also distributed across regions according to the distribution in the STATENT. We use employment shares of a current year, since it seems difficult to project the development of regional employment.

For the formal representation of the estimation of regional employment we distinguish between the cantons of the plant sites k and the cantons m where employment is located.

- Employment in power plants is calculated as $emp_{s,g,m,t}^{plant} = emp_{s,g,k=m,t}^{plant}$
- Direct employment in supplying companies as

$$emp_{s,g,m,t,p,c,i}^{dir} = emp_{s,g,k,t,p,c,i}^{dir}\, regshr_{g,k,p,c,i} + \sum_k \left(emp_{s,g,k,t,p,c,i}^{dir} \left(1 - regshr_{g,k,p,c,i}\right)\right) empshr_i^m$$

  with
  $regshr$ as the share of employment that is located in the site canton and
  $empshr$ as the share of employment in canton m and industry i in total employment in industry i according to the STATENT statistic
- Indirect employment in supplying companies (second and higher tiers) as

$$emp_{s,g,m,t,p,c,i}^{ind} = \sum_k emp_{s,g,k,t,p,c,i}^{ind}\, empshr_i^m$$

The estimation of employment in EDGE regions was done for the EXPANSE model. The Nexus-e model does not report its results by municipality and the OREES model does not report its results for the base year. This would be necessary for the employment estimation. For the estimation of employment in EDGE regions, a similar approach is utilised, but we additionally use the information on the plant site canton. We distinguish between the cantons of the plant sites r and the cantons q where employment is located.

Employment in power plants is assumed to be located in the municipality the plant is located in. The municipality is known from the output of the energy system model. It is calculated as

$$emp^{plant}_{s,g,q,t} = emp^{plant}_{s,g,r=q,t}$$

For direct employment in supplying companies, we additionally use the given information on the plant site canton and distribute the cantonal share of direct employment to EDGE regions within the canton according to the share in the STATENT statistic. It is calculated as

$$emp^{dir}_{s,g,q,t,p,c,i} = emp^{dir}_{s,g,k,t,p,c,i} \times regshr_{g,k,p,c,i} \times empshr^{i,k}_{i,q} + \sum_{r} \left(emp^{dir}_{s,g,r,t,p,c,i} \left(1 - regshr_{g,q,p,c,i}\right)\right) empshr^{q}_{i}$$

with

- $regshr$ as the share of employment that is located in the site canton,
- $empshr^{i,k}_{i,q}$ as the share of employment in industry i in region q in employment in industry i in canton k
- $empshr$ as the share of employment in canton m and industry i in total employment in industry i according to the STATENT statistic

The calculation of indirect employment in supplying companies (second and higher tiers) follows the calculation for cantons:

$$emp^{ind}_{s,g,q,t,p,c,i} = \sum_{r} emp^{ind}_{s,g,r,t,p,c,i}\, empshr^{q}_{i}$$

2.3 Data

In the following, the data used for estimating employment impacts according to the method explained above is described.

Capacities

Installed capacities by scenario, technology and region for the year 2035 are given as results of the energy system models. Installed capacities for a base year were not available for every model. For the EXPANSE model, data were available for the base year 2018, for Nexus-e data were available for 2020. For OREES we used the data from the EXPANSE model. With the model-specific base year data we calculated the annual development of installed capacities by assuming a linear development until 2035. Annual capacities installed were derived from the development of installed capacities.

For nuclear power plants we assumed a phase-out after 60 operation years and latest in 2034. The nuclear power plant Mühleberg was shut down at the end of 2019 and currently is in the post-operation phase. For the plants Beznau I and Beznau II, the last operation years are 2029 and 2031. The plants Gösgen and Leibstadt would still be operational in 2035 when assuming 60 operation years. In line with the assumption of a phase out before 2035, we assumed the last operation year of the Gösgen plant to be 2032 and that of the Leibstadt plant to be 2034. According to a study on the costs of decommissioning nuclear power plants by Swissnuclear (2021a), these undergo two phases after shutdown, the post-operation phase with a duration of 4-5 years and the dismantling phase with a duration of 10 – 11 years. In the Swissnuclear study, these phases, including costs and employment, are planned for each plant (Swissnuclear 2021b, Swissnuclear 2021c). The plant specific capacity under dismantling results from the last operation year and the duration of the two post-operation phases.

Expenditures and cost structures

Expenditures for investment, O&M and dismantling are generally calculated by multiplying capacity data with technology specific costs. For the allocation to cost components and supplying industries, we need data on cost structures. Table 2 contains an overview of the sources used to determine specific costs and cost structures. Specific costs are also used by the energy system models as inputs, but they differ between models. To make sure that differences of employment impacts between models only depend on differences in capacity development, we used one set of cost data for all models.

Costs were collected for the years 2020 and 2035 and interpolated for the intermediate years, if cost changes are anticipated in the sources. Investment costs for construction of new hydro power plants are taken from Prognos (2007) that allows to differentiate between the different plant types. Piot (2018) is the source for replacement investments during the lifetime of hydro power plants and O&M costs were taken from Filippini/Geissmann (2018). Investment costs of PV plants scale significantly with increasing capacity and are assumed to decrease substantially until 2035. We calculated weighted average costs across plant sizes based on data from the SCCER Joint Activity Scenarios and Modelling (JASM) project (PSI 2020). Regarding biomass and waste-to-energy (MSW incineration plants), the EXPANSE model considers solid biomass, biogas and waste-to-energy. Nexus-e only considers waste-to-energy, while OREES does not include this category at all. For this heterogeneous category, we calculated average unweighted costs for incineration plants and

for wood CHP plants (1 MW class) based on Rytec (2010) and PSI (2020). Costs for gas-fired plants are a weighted mix of large combined cycle plants (IGCC) and smaller (100 kW_{el}) CHP plants with the share in installed capacity in 2021 used as weights. For nuclear power plants, expenditures for investment in new plants is not relevant due to the phasing-out assumption. Specific expenditures for investment during the operation phase was taken as long-term averages from annual reports of the Gösgen (KKG 2024) and the Leibstadt plant (KKL 2024). These were also the basis for the specific O&M expenditures. In the case of dismantling of nuclear power plants, we use data from Swissnuclear (2021b, 2021c) on the costs of post-operation, decommissioning and disposal, that also contains for each nuclear power plant estimates on labour demand for decommissioning.

The investment, O&M and dismantling expenditures are broken down by cost components and allocated to supplying industries. Data on cost structures of power plants are rare. Our sources for cost structures of power plants (breakdown of costs to cost components) are data published in Breitschopf et al. (2012) for power plants based on renewable sources, company annual reports for nuclear power plants, Filippini / Geissmann (2018) for hydro power plants, a market survey and a projection on costs and cost components of PV systems (Bloch/Sauter 2024 and Bauer et al. 2019). The allocation of cost components to supplying industries stems from own assumptions based on the description of the cost components.

Technology	Sources for cost data	Sources for cost structures
Hydro run of river	Prognos (2007), Filippini/Geissmann (2018), Piot (2018)	Breitschopf et al. (2012), Filippini/Geissmann (2018)
Hydro storage	Prognos (2007), Filippini/Geissmann (2018), Piot (2018)	Breitschopf et al. (2012), Filippini/Geissmann (2018)
Hydro pumped storage	Prognos (2007), Filippini/Geissmann (2018), Piot (2018)	Breitschopf et al. (2012), Filippini/Geissmann (2018)
Photovoltaic	PSI (2020)	Bloch/Sauter (2024), Bauer et al. (2019), BFE (2017)
Wind energy	Panos et al. (2023)	Breitschopf et al. (2012)
Waste to energy	Rytec (2010)	Breitschopf et al. (2012)
Wood CHP plant (1 MW)	PSI (2020)	Breitschopf et al. (2012)
Gas (IGCC / gas CHP)	PSI (2020)	JICA (n.d.)
Nuclear power plants	KKG (2024), KKL (2024), Swissnuclear (2021b, 2021c)	KKG (2024), KKL (2024), Swissnuclear (2021b, 2021c)
Batteries	EXPANSE model inputs	–

Table 2: Sources for data on costs and cost structures. Own presentation

Employment

Generally, employment in plant operation is calculated from labour costs. For nuclear power plants, we used plant specific employment data from annual reports and other company data (KKG 2024, KKL 2024, BKW 2023) and kept employment constant during the post-operation phase, based on the experiences with the shut-down of the Mühleberg plant (BKW 2023). Employment in forestry for the supply of wood for biomass plants was calculated as an employment factor based on statistical data of employment in forestry and on the use of domestic wood for electricity generation in woody biomass plants. Employment in the gas supply industry for the supply of gas to gas-fired power and CHP plants was derived from data in the energy IOT 2014 (Nathani et al. 2019).

Import and regional shares

The setting of import and regional shares can have a significant impact on the employment results. If no shares are set, industry specific import shares and regional shares are used as default values. Since a comprehensive assessment of the supply chain activities for electricity generation was not possible in this project, we focused on economic activities in the PV supply chain, since PV is the renewable energy technology with the largest growth in the scenarios.

Table 3 contains an overview of the components of PV plants, their shares in total investment costs and the import and cantonal shares for each component that we have assumed. PV modules and inverters are important parts of PV plants. Both are almost completely imported according to the Swiss solar energy statistics (SFOE 2024b) and information from industry experts. Regarding wiring and electrical machinery and for carrying constructions, domestic

companies do exist (e.g. Stäubli, Ernst Schweizer), but their market share in Switzerland is unknown. We therefore do not set import shares but use the industry specific default values from the IOT. Regarding cantonal shares, we assume that planning, site preparation, transport and installation are done by companies located in the site region. The cantonal share is reduced by up to 40 percentage points, the smaller the area of the canton is.

We decided for every cost component of every technology whether available information or plausible assumptions justified the setting of import and cantonal shares. For wind power plants, we set the import share of wind turbine nacelles, rotor blades and towers to 100% as well as on-site installation of the wind turbines, that we assume to be done by the foreign manufacturers with their own employees. For nuclear power plants, fuel elements also completely stem from abroad. The import share was generally set to zero for planning and engineering, construction, installation (with the exception of wind power plants) and connection to the power net, transport activities, regulatory activities, wood supply, insurance or waste management. Cantonal shares were set to 100% for activities such as wood supply, unspecialised planning, construction and connection to the power net, regulatory activities (with the exception of nuclear power plants, where these are located at the federal level) and waste management.

Component of PV plant	Share of investment costs	Import share	Cantonal share
Planning	7%	0%	100%
PV module	23%	98%	0%
Carrying construction, metals	8%	n.s.	0%
Wiring, electrical machinery	7%	n.s.	0%
Inverter	8%	100%	0%
Wholesale	11%	0%	0%
Site preparation	9%	0%	100%
Transport	3%	0%	100%
Installation	25%	0%	100%
Total	**100%**		**44%**

Table 3: Import shares and cantonal shares of PV cost components. Sources: Bloch/Sauter (2024), Bauer et al. (2019), own assumptions, n.s. = not specified

Data from the STATENT 2019 are used to calculate regional employment shares by canton or EDGE region within industries. We preferred the year 2019 to the more recent, but Covid-distorted years 2020 and 2021.

Input-output model

In this report, we use the Swiss energy-oriented input-output table (energy IOT) for the reference year 2014, developed by Nathani et al. (2019). This table has the advantage that the energy sector is more disaggregated than in the official Swiss IOT and that the quality of the energy data has been improved. Within the energy supply industry, electricity supply is separated from gas and district heat supply. And within electricity supply, several electricity generation technologies are distinguished and separated from electricity distribution and trade. We thus assume a constant economic structure until 2035. Labour productivities were projected to the year 2035 based on the results of the economic projections for the Federal Chancellery (Cretegny/Müller 2020).

3 Results

In this chapter the results on the employment requirements and impacts of the transition to an electricity system based largely on renewable energy sources are presented. Given the large number of scenarios calculated by the three energy models, we focus on the main scenarios and only present selected results for all scenarios. For the presentation of more detail and the dynamics between 2021 and 2035, we choose the HighRES35 scenario as an intermediate scenario and the EXPANSE model as the model with the largest technological variety. The results of the three models are not exactly comparable, since the Nexus-e model doesn't include woody biomass and biogas and the OREES model doesn't include gas, biomass and waste-to-energy.

3.1 National employment impacts

The expenditures for the energy transition are the starting point of our calculations. They are displayed in the following in order to enhance the understanding of employment impacts. Figure 2

shows the investment, O&M and dismantling expenditures in the year 2035 by technology for the four main scenarios and the three energy models. Depending on the scenario and the model, the investment expenditures range between one and two billion CHF, with hydro power and PV plants as dominating technologies. The expenditures, especially for PV plants, generally increase with the ambition level of renewable energy targets set in the scenarios. They are lowest for the RES35 scenario and highest for the Solar35 and the VeryHighRES35 scenarios. Investment in hydro power plants is mainly replacement investment, since the energy models project no or rather low-capacity expansion. Investment expenditures for PV are highest in the Nexus-e model results, while the EXPANSE and the OREES models project higher expenditures for wind and biomass[1] technologies. The expenditures for operation and maintenance of power plants range between two and three billion CHF. They are dominated by hydro power plants due to the nuclear phase-out before 2035. PV and wind power plants are more capital intensive but need less operation and maintenance activities.

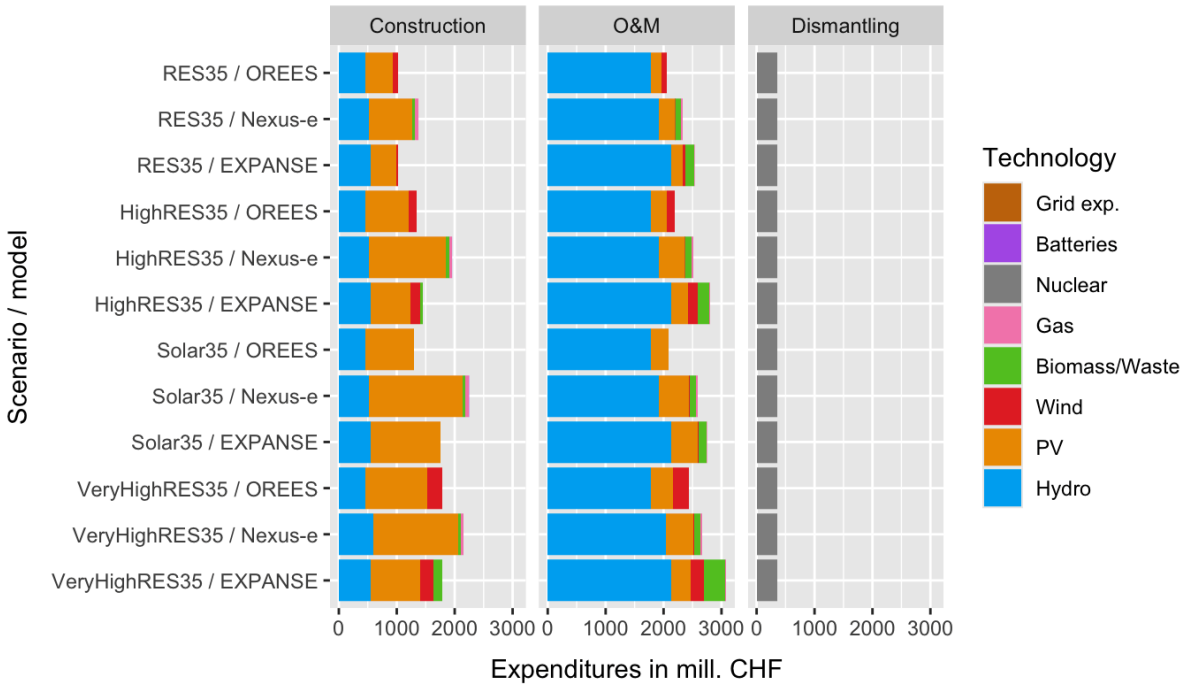


Figure 2: Expenditures for power plants in 2035 by technology and life-cycle phase of power plants: comparison between models and scenarios. Own calculations based on Heinisch et al. (2023)

The dismantling expenditures are much lower than investment and O&M expenditures (approx. 350 million CHF). They refer solely to nuclear power plants and are practically identical in all scenarios. Expenditures for batteries and grid expansion are not relevant according to the results of the energy models.

The development of expenditures between the first and the last year of our analysis (2021 and 2035) is shown in Figure 3 for the case of the HighRES35 scenario and the EXPANSE model. The development is comparable for other combinations of models and scenarios. Even though we assume a constant capacity expansion between 2020 and 2035, investment expenditures are decreasing. This is due to the decreasing costs of PV plants. Investment expenditures for nuclear power also decrease according to the phase-out scheme of the individual plants. O&M expenditures increase until 2029 and then decrease substantially. The increase is driven by the capacity expansion of PV, wind and biomass plants. The decrease again mirrors the phase-out of nuclear power plants until 2035. The phase-out also drives the dismantling expenditures. The expenditures before 2030 refer to the Mühleberg plant in the canton of Berne that was shut down at the end of 2019.

[1] including waste-to-energy plants in the rest of the report

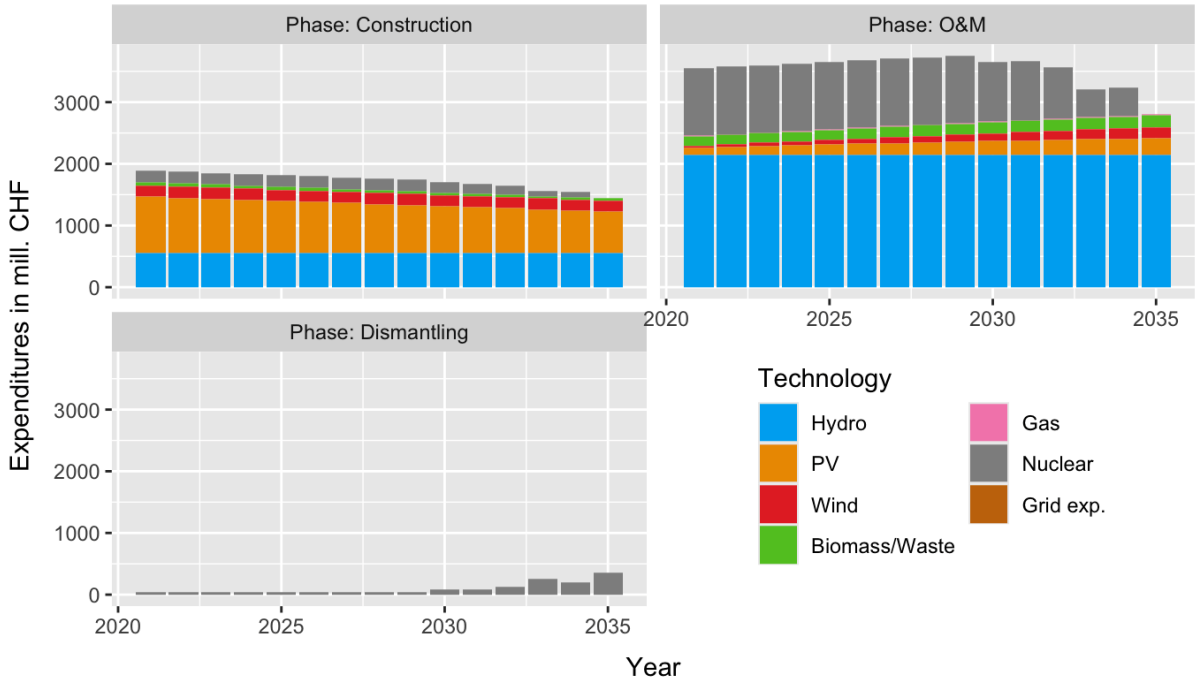


Figure 3: Development of expenditures for power plants between 2021 and 2035 in the HighRES35 scenario, by technology and life-cycle phase (based on results of the EXPANSE model). Own calculations based on Heinisch et al. (2023)

The level of employment induced by the investment in power plants, their operation and maintenance and dismantling mainly depends on the level of the respective expenditures, the share of expenditures that goes to companies abroad (import share) and the employment intensity of economic activities that are induced in Switzerland, either directly or indirectly in the supply chains. Figure 4 displays the development of employment induced by power generation between 2021 and 2035 for every combination of models and scenarios. The darker lines show the development for the main scenarios (three for every main scenario, one for each model). The employment impact is presented as fulltime equivalent jobs, that summarises temporary jobs induced by investment and dismantling and permanent jobs in O&M of power plants.

In 2021, between 11 000 and 19 000 fulltime equivalent jobs are required. The numbers decrease to between 8 500 and 16 000 FTE in 2035 due to the cost reduction of PV plants and increasing labour productivity. Again, employment increases with the ambition level of the RE targets. It is lowest for the RES35 scenarios and highest for the Solar35 scenarios. Employment is lowest for the OREES results, since hydro capacities are lower and this model optimises for the most productive PV and wind power plant locations and thus projects lower investment expenditures.

It is important to note that the development between 2021 and today (2025) does not reflect the actual development of employment impacts. Since the energy models only produce results for the year 2035, the annual data are linear interpolations between the data for the model base years and the results for the year 2035. To put the results in perspective: the average capacity of PV plants increased between 2020 and 2024 by 1.3 GW on average. This approximately equals the average annual capacity increase assumed by the Nexus-e model for the HighRES35 scenario. The actual capacity increase of PV plants in the year 2024 was already higher than the average capacity increase assumed in the most ambitious scenario. Thus, the employment impacts for the years 2021 to 2025 probably underestimate the actual development.

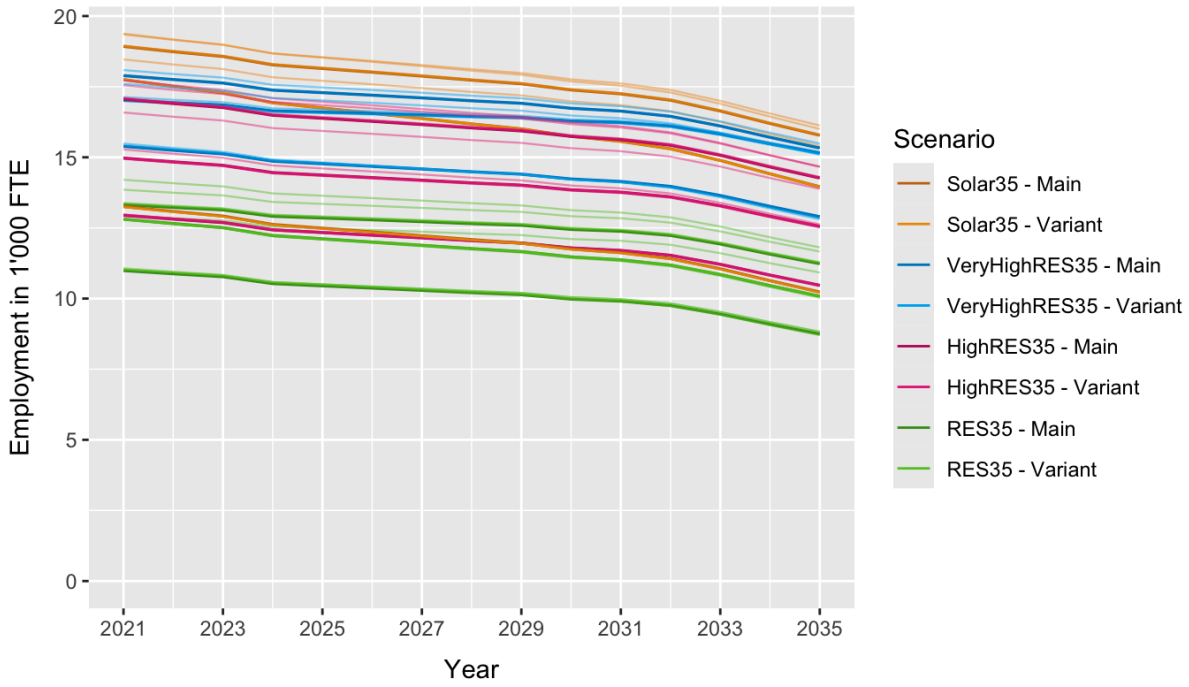


Figure 4: Development of employment induced by power generation between 2021 and 2035 for every model-scenario combination. Own calculations

The employment induced by power generation in the year 2035 is shown in more detail in Figure 5. The operation and maintenance phase is disaggregated into operation of power plants, supply of goods and services for O&M and fuel supply. Employment required by the construction of new power plants and replacement investments accounts for 3 000 to 8 000 jobs, depending on the scenario and the energy model. To a certain degree, the employment patterns resemble the cost patterns in Figure 2.

With regard to investment, PV plants have the major share in employment. Employment is larger for the Nexus-e model that projects higher capacity increases and investment expenditures. Wind energy and biomass play a minor role. The pattern is different for the operation of power plants, where hydro power plants and partly biomass plants account for the major share of jobs (between 1 200 and 4 000). By contrast, PV plants are irrelevant. The EXPANSE results are higher for jobs in biomass power plants. The production of goods and services needed for the O&M of power plants accounts for 2 000 to more than 3 500 jobs. Here, hydro power and PV plants are responsible for most of the jobs. The differences between models mainly reflect the different expansion pathways of PV and wind power plants. Regarding fuel supplies, we account for employment in forestry (only EXPANSE) and gas supply. The number of jobs is small compared to the other life-cycle phases. Finally dismantling of nuclear power plants is responsible for almost 2 000 jobs in 2035. Apart from the Mühleberg plant, that is foreseen to reach the end of the dismantling phase by 2033, all other plants are in the post-operation or the dismantling phase.

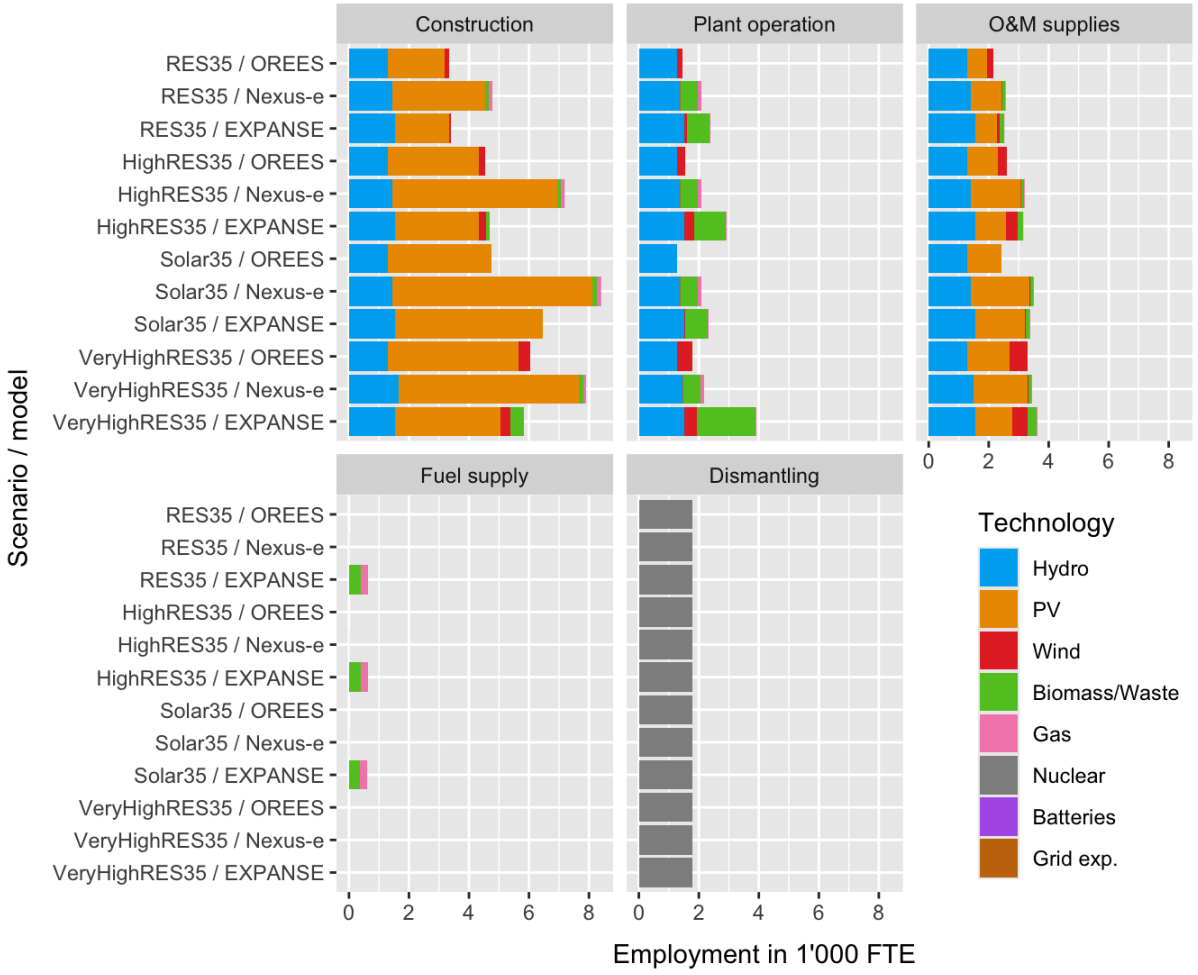


Figure 5: Employment induced by power generation in 2035 by life-cycle phase and technology: comparison between models and scenarios. Own calculations

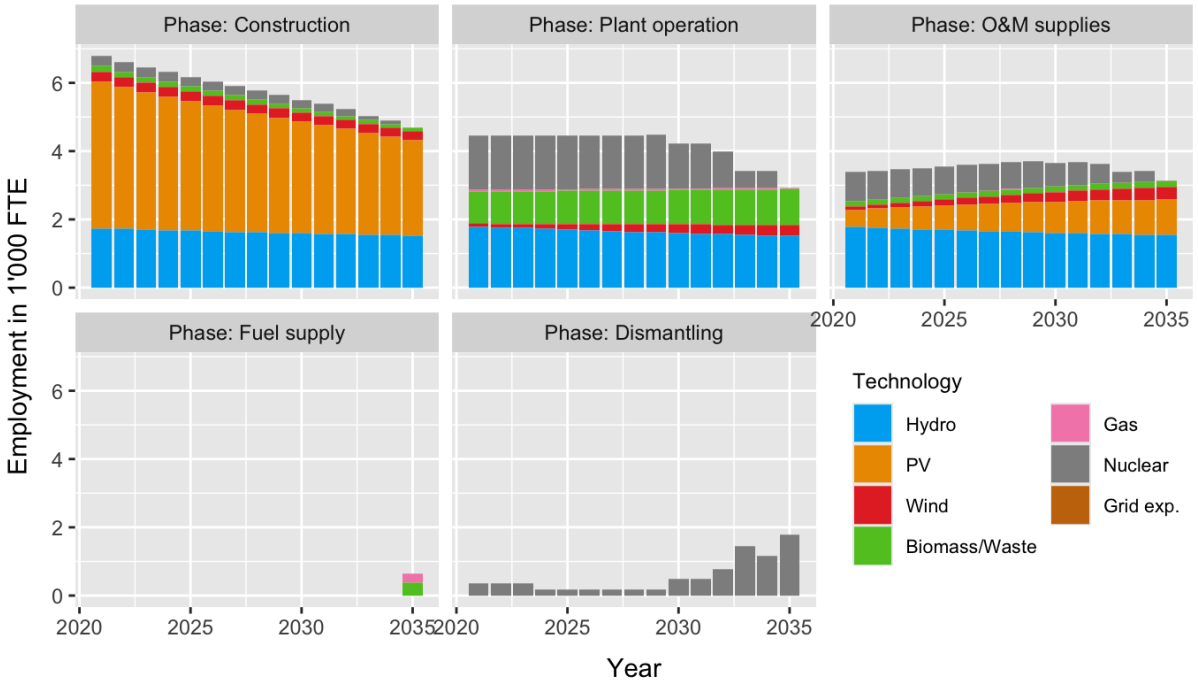


Figure 6: Development of employment by life-cycle phase and technology, 2021-2035, based on the results of the EXPANSE model for the HighRES35 scenario. Own calculations

The temporal development of employment by technology and life-cycle phase is displayed in Figure 6 for the results of the EXPANSE model for the HighRES35 scenario. It generally resembles the pattern of cost development. Employment induced by the construction of new plants and replacement investments gradually decreases from 6 800 FTE in 2021 to 4 700 FTE in 2035. The downward slope of employment is stronger than that for investment costs, since increasing labour productivity adds to the impact of cost reduction. The operation of power plants requires more than 4 000 FTE in 2021 and stays constant until 2029. Decreasing employment in hydro power plants due to labour productivity increase is offset by operation of additional wind power and biomass plants. Beginning in 2030, the phase-out of nuclear power plants reduces employment to 3 000 FTE in 2035. Employment induced by O&M supplies increases from 3 300 FTE in 2021 to a high of 3 800 FTE in 2029 due to new PV, wind and biomass power plants. From 2030 on, employment decreases to more than 3 000 FTE due to nuclear phase-out. Employment induced by fuel supply is only available for the year 2035 and amounts to approximately 700 FTE. Employment from dismantling of nuclear power plants starts to increase in 2030 and reaches a high of almost 2 000 FTE in 2035.

Figure 7 displays the breakdown of employment in 2035 by industry for the four main scenarios and the three energy models. Most of the jobs are required in the power plants (operation of hydro power plants and dismantling of nuclear power plants) and in the construction industry.

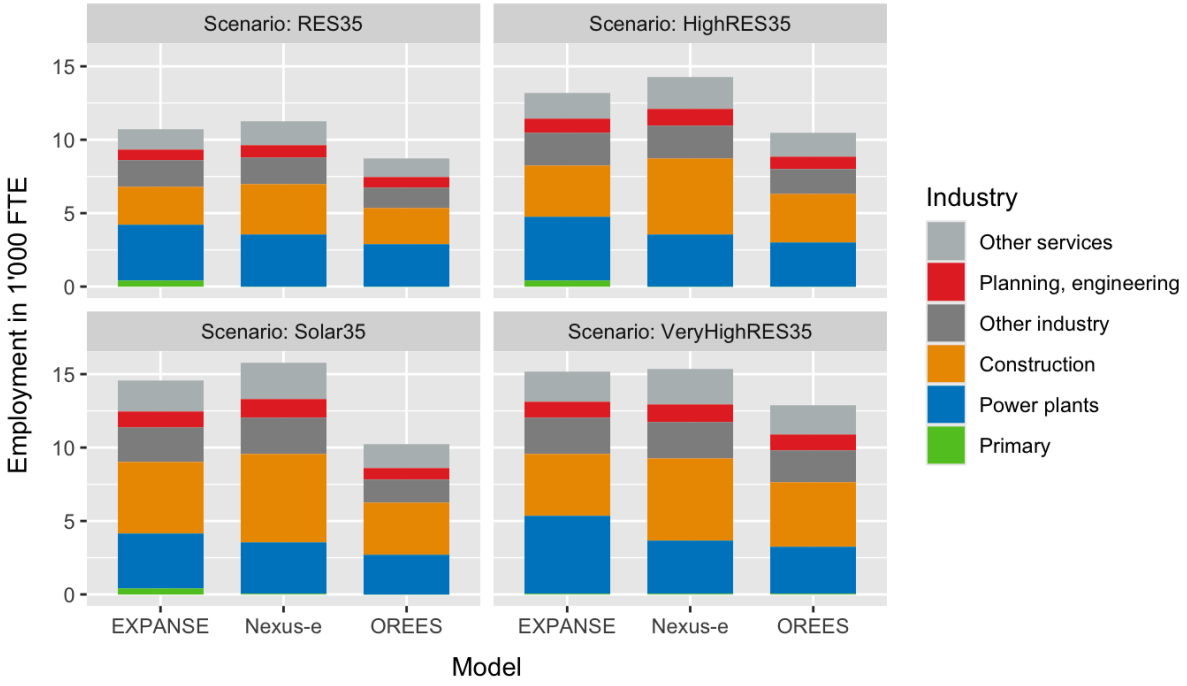


Figure 7: Employment by industry in 2035 in the four scenarios, based on results of the EXPANSE model. Own calculations

Note: Employment in the primary sector is missing in the VeryHighRES35 scenario, since the energy models do not report results for woody biomass.

The rest of the industry sector also plays a certain role, even though many industrial components of new renewable power plants are imported (e.g. PV modules, inverters and wind turbines). The high importance of construction and also of planning and engineering in the service sector reflects the strong relevance of capacity addition in the transformation of the electricity system. Employment in the rest of the service sector is also relevant, while employment in the primary sector is negligible.

3.2 Regional employment impacts

The regional employment impacts are displayed for cantons on the one hand and for EDGE regions on the other hand.

Regional employment impacts by canton

The estimation of cantonal employment impacts is based on the expenditures for investment in, O&M

and dismantling of power plants by site canton[2]. Figure 8 displays a comparison of expenditures by canton and technology for the first and the last year of our analysis period and the results of the EXPANSE model for the HighRES35 scenario. The results for the two years mainly differ with regard to nuclear power plants. While four plants are operational and only one is in the post-operation phase in 2021, all plants are out of operation in 2035, so that the costs only reflect post-operation and dismantling. For the other technologies, results are similar due to the assumption of constant expansion of capacities between 2020 and 2035. For the two cantons that host nuclear power plants, the expenditures for renewable power plants are much lower than those for nuclear power plants, so that a first distributional impact of the energy transition becomes apparent.

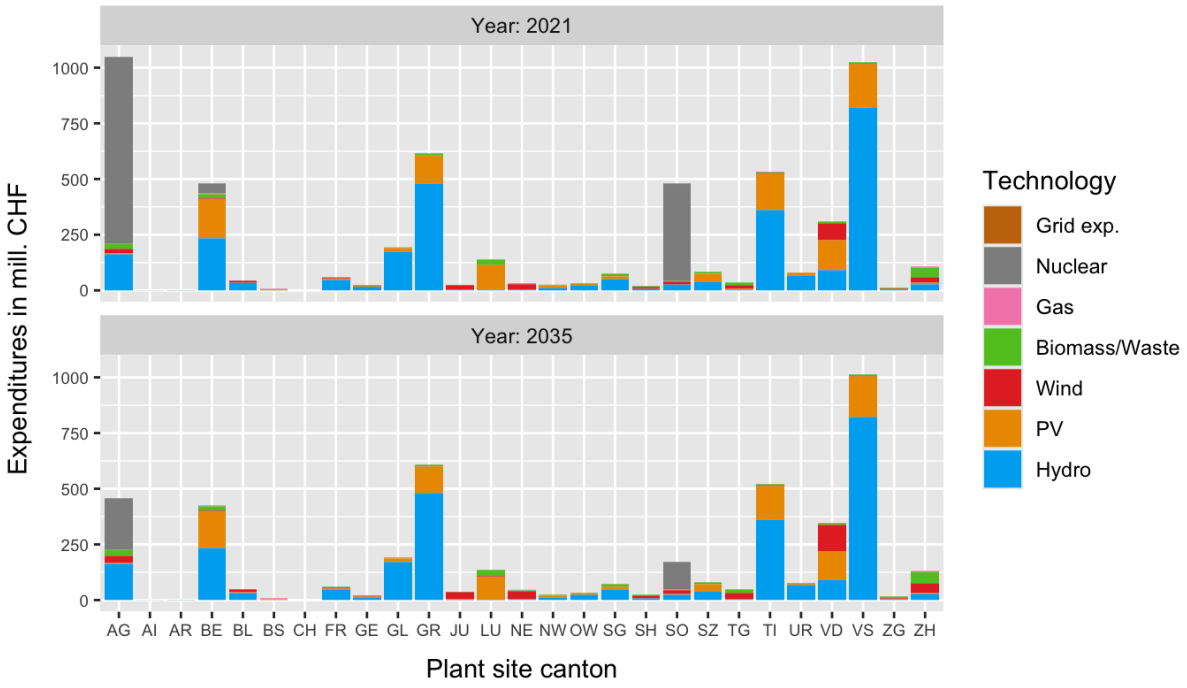


Figure 8: Expenditures for power plants by technology and canton in 2021 and 2035. Own calculations based on Heinisch et al. (2023)

Regarding the expenditures for power plants based on renewable sources, expenditures for (mainly pre-existing) hydro power plants are concentrated in the alpine cantons of Berne, Graubünden, Wallis and Ticino. The expenditures for PV and wind power plants mainly refer to new plants. The cantons strong in hydro power also receive a significant share of PV-related expenditures with some additional cantons such as Lucerne and Vaud. Expenditures for biomass are additionally allocated to the cantons of Zurich and Aargau. Compared to the EXPANSE model results, the expenditures for PV plants are more evenly distributed in the results of the Nexus-e model and are more concentrated in the results of the OREES model.

Figure 9 contains an overview of employment impacts in 2035 by canton for a combination of the three energy models and four main scenarios. Apart from the well-known observation that employment impacts tend to increase with the ambition level of the scenarios, the following observations can be made. Firstly, the plot shows a significant variation of employment impacts between combinations of models and scenarios. The variation also differs strongly between cantons (low variation for Solothurn vs. large variation for Berne). Secondly, the cantons with large employment impacts include the cantons with high expenditures, but also some cantons that seem to profit from indirect impacts due to their strong economic base (e.g. the cantons of Zurich, St. Gallen and Vaud).

[2] The canton (or region) a power plant is located in.

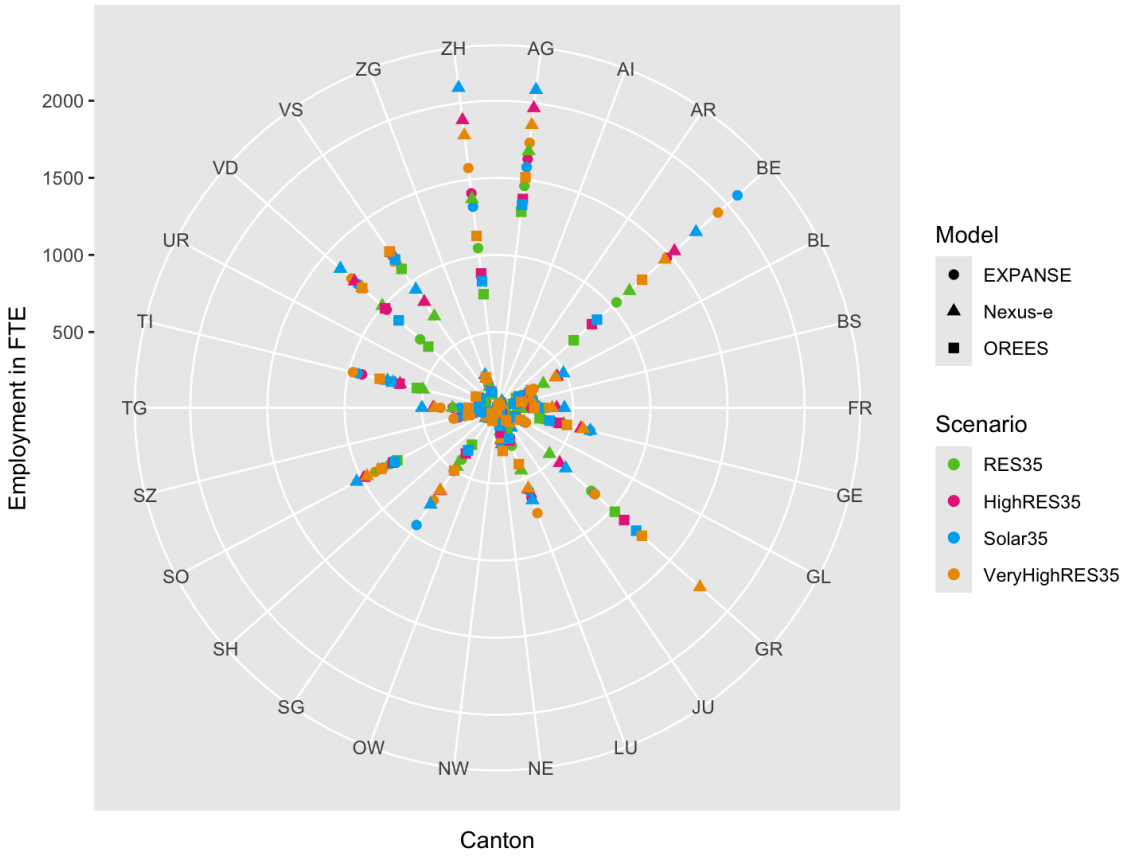


Figure 9: Employment induced by power generation in 2035 by canton: combination of models and main scenarios. Own calculations

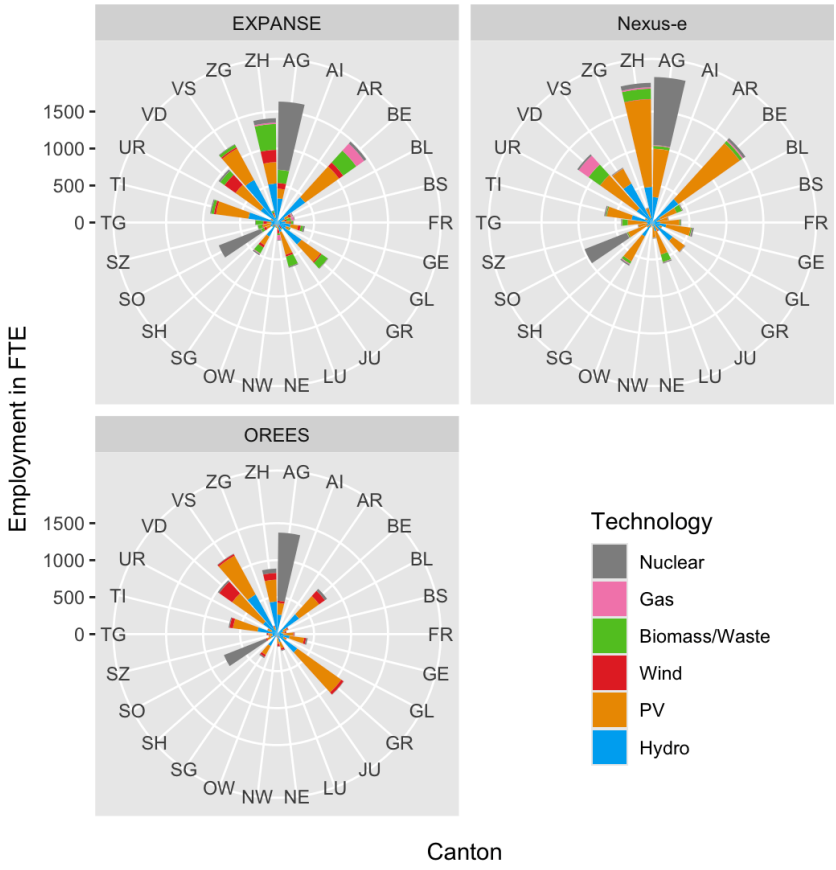


Figure 10: Comparison of employment impacts in 2035 by canton and technology between models. Own calculations

Figure 10 compares the employment impacts by canton and technology between the three models for the “HighRES35” scenario. The results are almost identical for hydro and nuclear technology, they mainly differ for PV, wind, biomass and gas. The employment impacts based on the EXPANSE results display the largest technological variety with noteworthy shares for biomass. The employment impacts based on the Nexus-e results focus strongly on PV, with wind playing no role at all and biomass being less relevant. Furthermore, PV is projected to be installed in more cantons than in the EXPANSE results. Noteworthy is the much smaller employment impact in the canton Graubünden compared to the EXPANSE and the OREES results. Employment is higher for the Nexus-e model results due to stronger PV deployment with less productive sites and larger investment costs. Gas is projected to be focused in the canton of Vaud. The employment impacts based on the OREES results are significantly lower than for the other models. PV-related employment is lower due to smaller capacity increase and investment costs. Wind power plants are projected to be installed in several cantons, similar to the EXPANSE model.

Figure 11 illustrates the differences between the scenarios for the results of the EXPANSE model. The results mainly differ with regard to PV, wind and biomass. Employment increases with increasing RE targets in the scenarios. Generally, all cantons witness increasing employment, but it appears that some cantons already reach their potential in the low-target scenarios, e.g. Valais, Graubünden and Ticino, while employment in other cantons grow across all scenarios (e.g. Zurich, Berne, Lucerne and St. Gallen). In the HighRES35 and the VeryHighRES35 scenarios, employment induced by wind and biomass increase more than in the Solar35 scenario, where PV is the dominating technology.

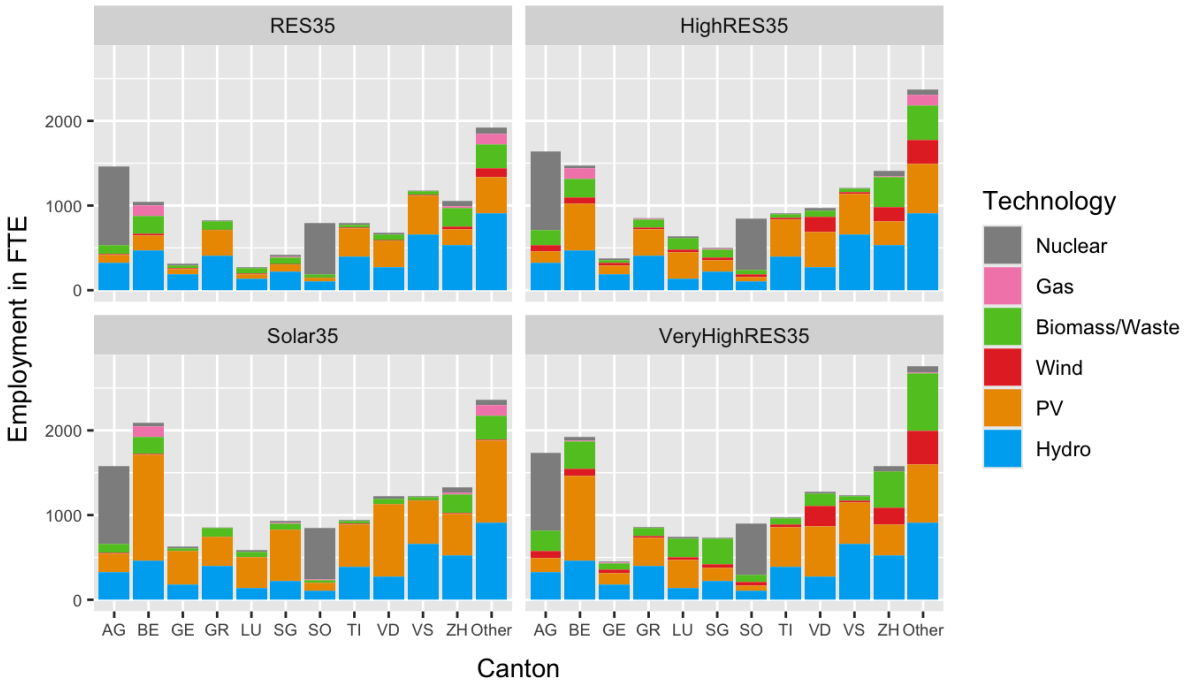


Figure 11: Employment impacts in 2035 by canton and technology, based on results of the EXPANSE model. Own calculations

The technology pattern of RETD in the cantons also determines, which life-cycle phase is important for employment (Figure 12). For cantons that mainly rely on PV deployment, employment mainly happens in the construction phase and to a lesser extent in the operation phase. This also means that employment will decrease as soon as the investment dynamics decrease.

For cantons with a larger share of hydro and biomass power plants, the operation phase (including fuel supply) becomes more relevant and, additionally, the jobs are rather stable over the operation period. And for cantons with nuclear power plants, the dismantling phase is an important factor for employment.

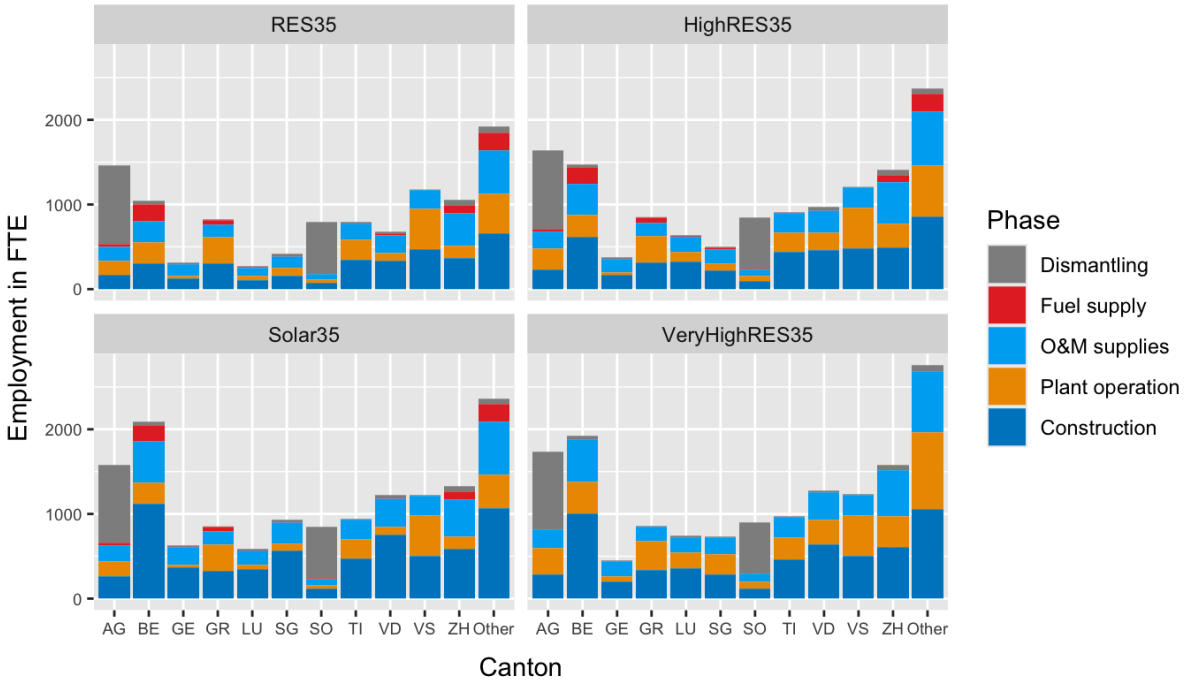


Figure 12: Employment impacts in 2035 by canton and life cycle phase, based on results of the EXPANSE model. Own calculations

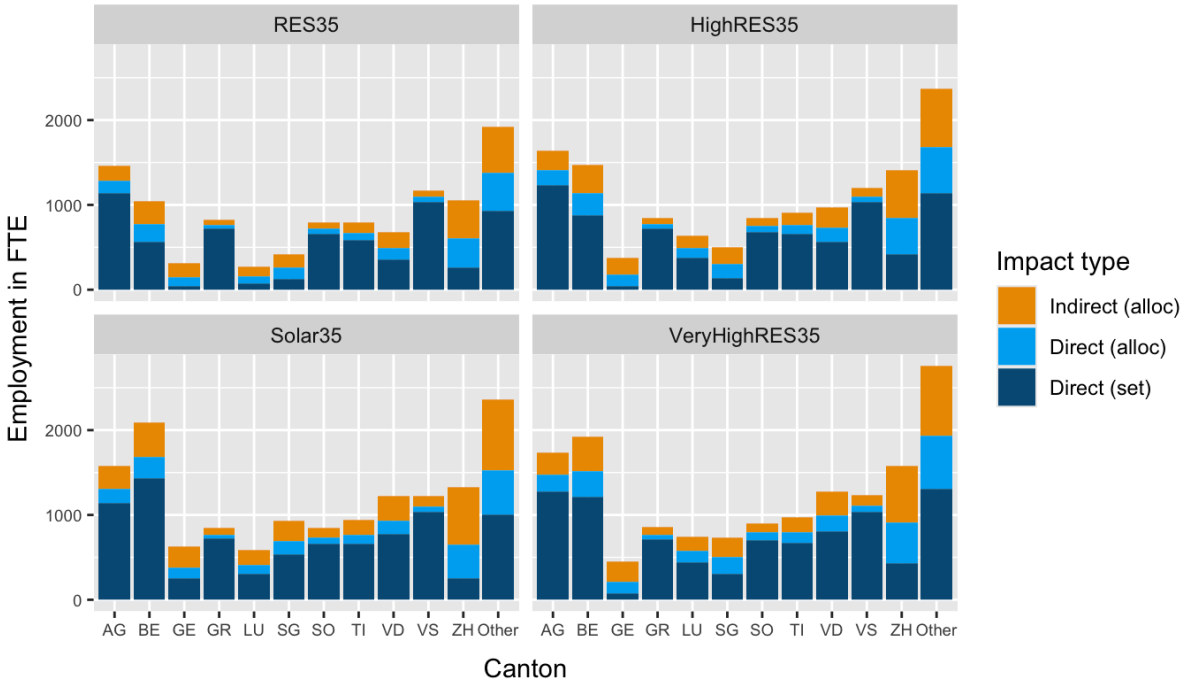


Figure 13: Employment impacts in 2035 by canton and impact type, based on the results of the EXPANSE model. Own calculations

Figure 13 displays the cantonal employment impacts according to the type of impact and the way regional employment has been determined methodologically.

- Employment termed as “Direct (set)” is direct employment determined by the share that is assumed to be generated in the canton and employment in plant operation that is cantonal by definition.
- Employment termed as “Direct (allocated)” is direct employment determined by reallocation across cantons.
- Employment termed as “Indirect (allocated)” is indirect employment determined by reallocation across cantons.

The three categories are characterised by different levels of uncertainty and estimation improvement

potential. The first category is characterised by the lowest level of uncertainty. The second category is characterised by higher uncertainty and the largest potential for improvement of the regional allocation, since it seems possible to collect data on the regional distribution of companies active in the renewable energy technology field. The third category, i.e. employment in second and higher tiers of the supply chain, is also characterised by higher uncertainty, but the potential for improving regional allocation is low, since it does not seem possible to collect data on these companies. Furthermore, it appears to be realistic that the regional distribution of companies in higher tiers of the supply chains will approach the average industry specific regional distribution as seen in the employment statistics.

The analysis of Figure 13 shows that for many cantons (e.g. Aargau and Solothurn with their nuclear power plants, Graubünden and Valais with their hydro power and PV plants), the major share of employment belongs to the first category and thus appears to be quite certain. Some cantons are characterised by high shares of directly and indirectly allocated employment (e.g. Zurich and Geneva). They profit from their strong and diversified economic base that allows them to participate in supply chains induced by RETD in other cantons. These results for employment should be seen more as an employment potential of which it is uncertain, to what extent it is effectively realised in the cantons.

To put the absolute numbers in perspective, we compute for each scenario and every canton the share of the average annual employment between 2021 and 2035 (averaged across models and years) in total employment in the year 2019. In almost all cases, the employment share is below 1%, in most cases below 0.5% (Figure 18). The results show that the employment shares are higher for cantons in the alps (Glarus, Graubünden, Uri and Valais), that profit from the locations of renewable power plants, and cantons that host nuclear power plants. The share also depends on the size of the cantonal labour markets. For the canton of Zurich that has high absolute employment numbers, the relative share is small.

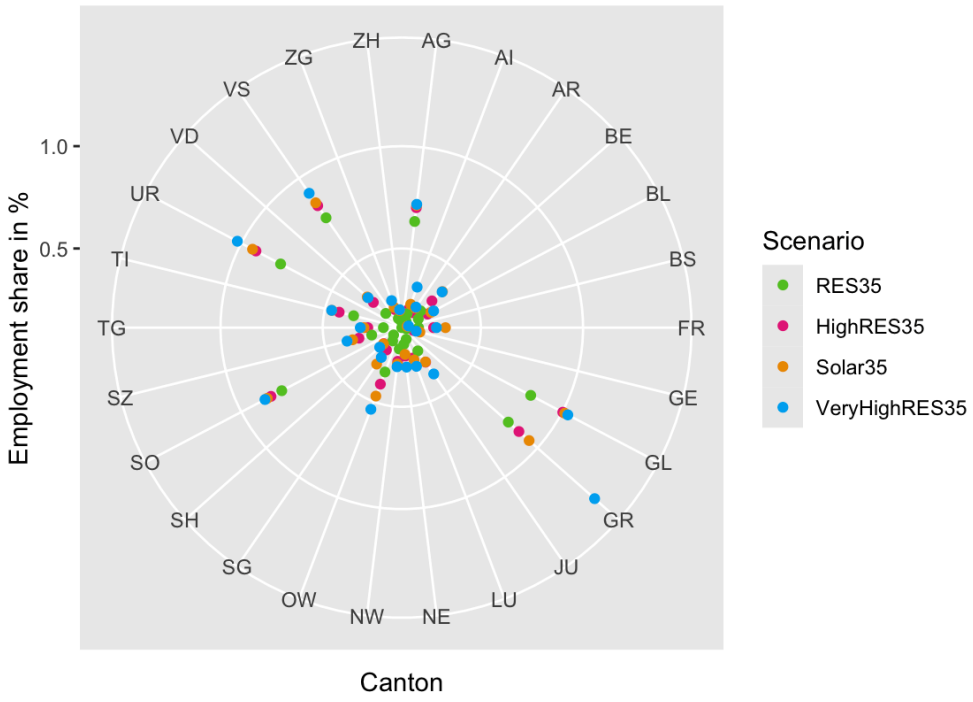


Figure 14: Share of jobs induced by power generation (average across models and between 2021 and 2035) in total regional employment 2019 by canton and scenario. Own calculations

Employment impacts in the EDGE regions

The employment impacts in EDGE regions were only estimated for the results of the EXPANSE model due to missing data for the other models. Since the standing capacities of hydro dams and pumped storage plants in 2035 were not available by municipality, these two technologies are not included in the following.

Figure 15 shows that in every scenario, employment is mostly generated in cities (between 5 000 and 7 500 FTE), followed by the midlands (1 800 – 3 000) and the alps (1 800 – 2 200). In the cities, all technologies are represented, with a particularly

large share for solar power. Hydro and solar power dominate in the alps, with some biomass but not much wind power. In the midlands, there is a mix of all technologies, depending on the scenario. Including hydro dams and pumped storage plants would probably lead to higher results for the alps due to employment for the operation of the plants, but also for suppliers in other regions.

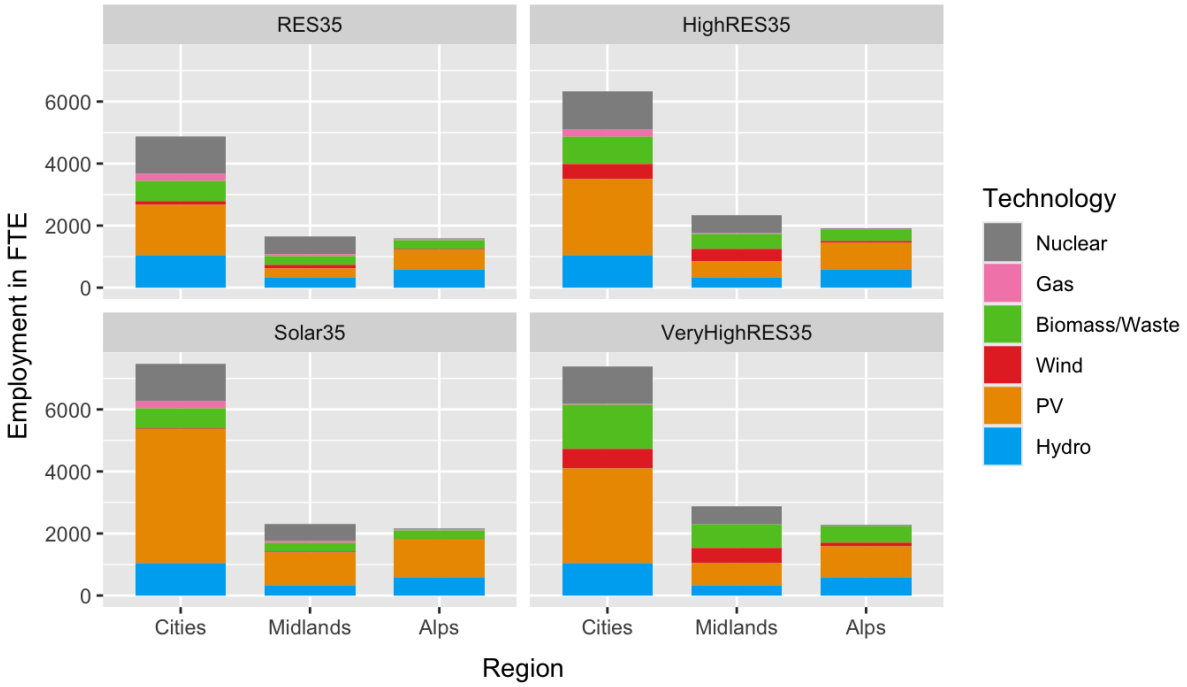


Figure 15: Employment in 2035 by EDGE region and technology. Own calculations

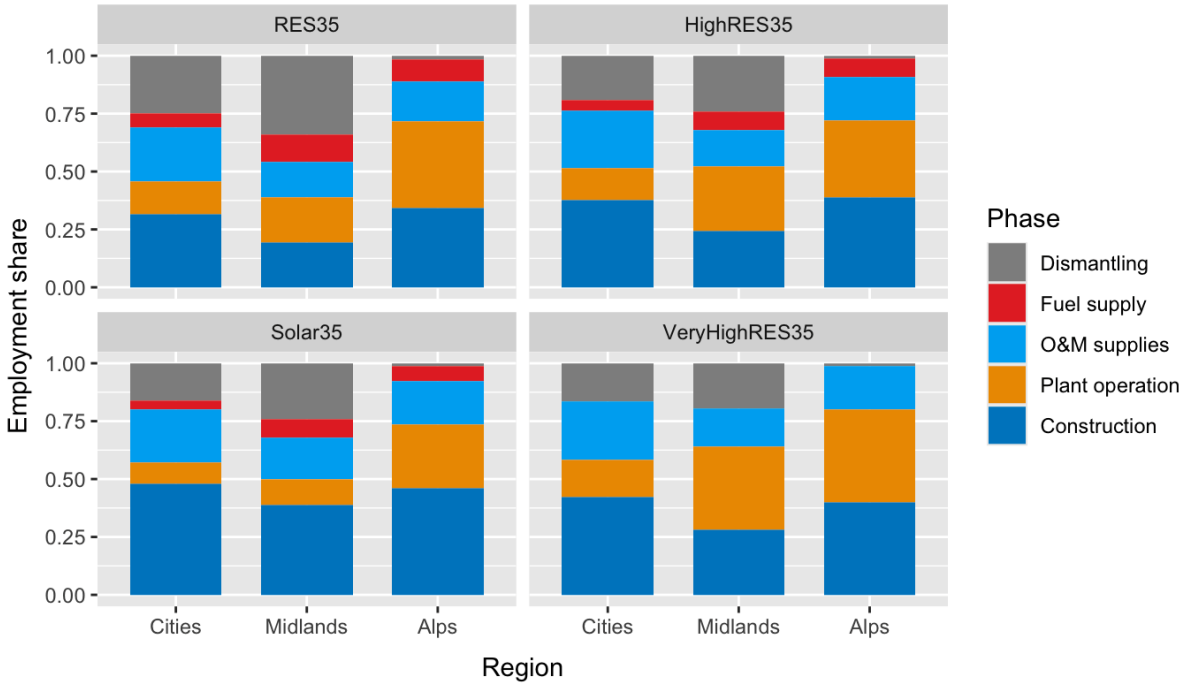


Figure 16: Employment in 2035 by EDGE region and life-cycle phase. Own calculations

Figure 16 shows a breakdown of regional employment by life-cycle phase. Construction and operation of power plants have especially high employment shares in the alps. These are activities that are either tied to the plant location or can be covered by regional companies, e.g. in the construction industry. The results may underestimate the role of specialised suppliers, e.g. for hydro power plants, that may be present in the alps due to the proximity of many hydro power plants. Data on their regional distribution are not available, but have been estimated from employment statistics.

Figure 17 displays a breakdown of regional employment by the type of impact (see text above Figure 13 for an explanation of the categories). It shows that in the alps, more than 75% of the jobs are either by definition tied to the plant location or can be assumed with large confidence to be located in the plant site region. Less than 10% are jobs that belong to direct suppliers, where the regional distribution has been statistically distributed and therefore is more uncertain. Up to 20% of the jobs belong to second- and higher-tier suppliers, for whom the assumption of an industry-specific regional distribution proportional to employment statistics seems more realistic. For the midlands and the cities, the share of jobs that have been allocated according to employment statistics is larger. This also reflects that fact that direct or indirect suppliers of power plants located in the alps are probably more often located in the cities and midlands.

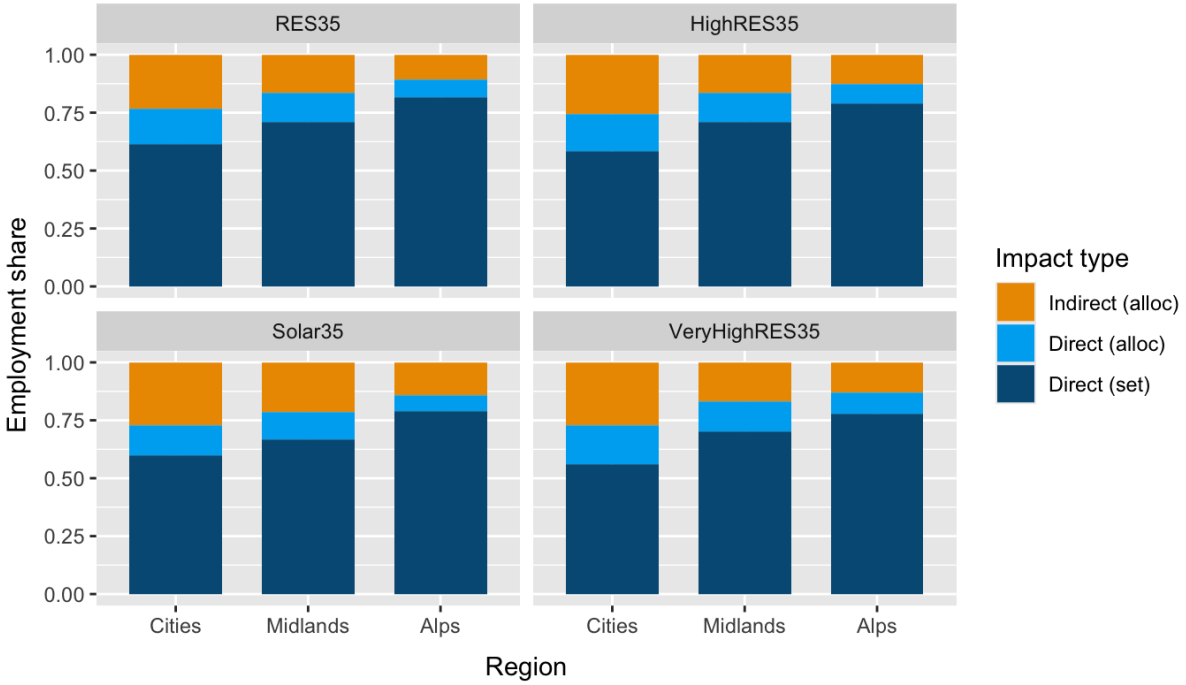


Figure 17: Employment in 2035 by EDGE region and life-cycle phase. Own calculations

To put the absolute numbers in perspective, we compute the share of the average employment between 2021 and 2035 in total employment for each region in the year 2019. Figure 18 shows that the employment share is largest for the alps (between 0.47% and 0.66%), followed by the midlands (0.34% – 0.52%) and the cities (0.22% - 0.32%). Thus, in relative terms, the alps profit most from employment induced by power generation with a high share of renewables, followed by the midlands and the cities.

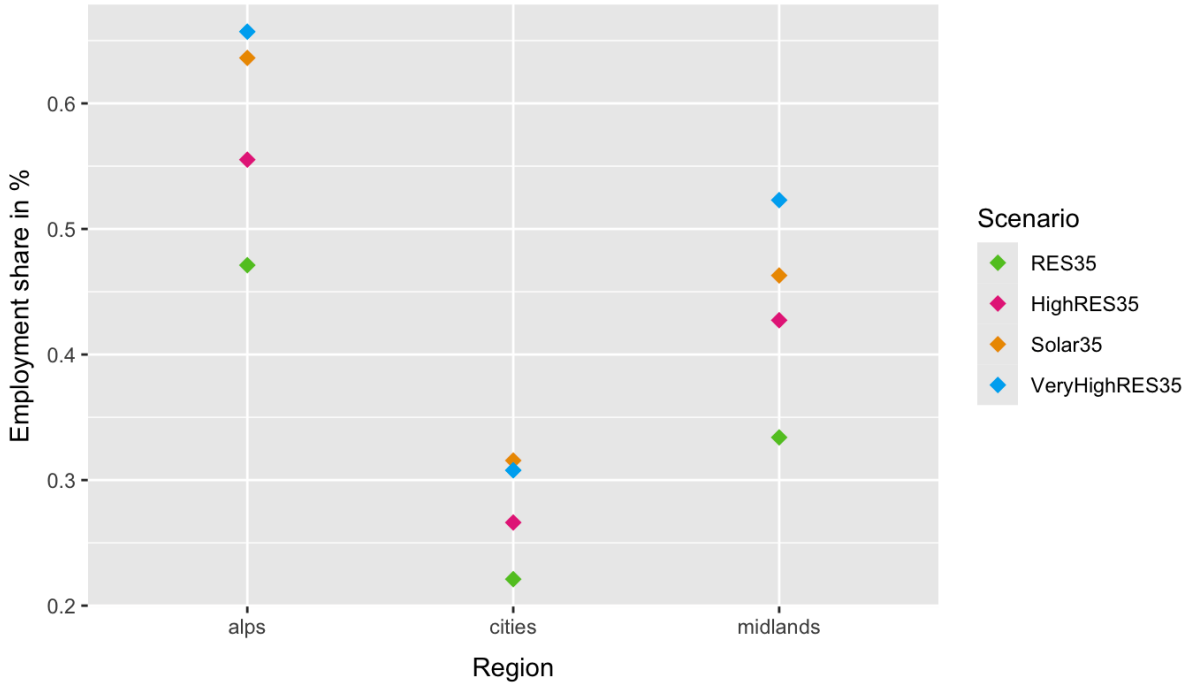


Figure 18: Share of average job requirement between 2021 and 2035 in total regional employment 2019 by EDGE region and scenario. Own calculations

4 Discussion and conclusion

At the national level, employment induced by power generation lies between 10 000 and 18 000 fulltime equivalents (average of the years 2021 – 2035, depending on the model and scenario). It increases with the ambition level of the renewable electricity target in the scenarios, since more construction of new PV and other power plants is initiated. Over time, the larger capacities also lead to more employment in operation and maintenance of existing plants. Employment per unit of added capacity will decrease due to decreasing investment costs of PV plants and increasing labour productivity. On the other hand, employment in nuclear power plants decreases due to the phase-out. Yet, the employment decrease is delayed beyond the year 2035 due to the long post-operation and dismantling period, sustaining employment for over a decade after the shutdown of nuclear power plants. Due to the strong capacity expansion, most of the generated jobs are linked to the construction of new plants. Employment for the operation of power plants and in suppliers for O&M is lower, but still substantial. Jobs in fuel supply (forestry and gas supply) are significantly lower. Jobs in dismantling of nuclear power plants are significant with almost 2 000 jobs in 2035.

Our results are comparable with the results of other studies. For PV we can derive an employment factor of 6.4 FTE per MW of new capacity installed. This is slightly higher than the employment factor reported in Koller/Perch-Nielsen (2024) for Switzerland, 6 FTE per MW, that do not fully include employment in the supply chains of constructing PV plants. The employment factor is substantially lower than those reported for PV in some international studies (e.g. collected in Ram et al. 2022). For wind energy, our employment factor is 3.8 FTE/MW, that is somewhat higher than, but comparable with the employment factor for wind onshore plants in Ram et al. (2022) for construction and installation, 3.2 FTE/MW. This could reflect the more complicated construction of wind power plants in Swiss landscapes. For biomass and waste-to-energy-plants we derive an employment factor of 12.5 FTE/MW that is comparable to the 14 FTE/MW in Ram et al. (2022). The employment factors for hydro and nuclear power plants are not comparable, since the values in the literature refer to the construction of new plants, while our results mainly refer to replacement investments.

At the regional level, we report results for cantons and EDGE regions (cities, midlands, alps). The regional employment impacts depend on the extent to which regions contain power plant locations and participate in the supply chains induced by constructing, operating and dismantling power plants. The relative importance of employment also depends on the size of regional economies. The regional employment impacts differ strongly

between models and scenarios. Employment generally increases with the ambition level of the scenarios, but the regional distribution differs between the models. It tends to be higher for the Nexus-e model than for the EXPANSE and the OREES model, since capacity expansion tends to be higher. It also tends to be more evenly distributed across cantons, since Nexus-e less strongly optimises for the most productive plant sites. The results at the cantonal level show that the shares of employment induced by power generation in total employment are higher for cantons in the alps (Glarus, Graubünden, Uri and Valais), that profit from the locations of renewable and for cantons that host nuclear power plants. It is also evident that in the long run, after the end of the dismantling period, the employment in the cantons of Aargau and Solothurn, that is related to power plants and their supply chains, will decrease due to the energy transition. In most other cantons, it will increase, so that employment in this small segment of the energy sector will be more evenly distributed across cantons.

For the EDGE regions, our results show that most of the jobs related to power generation will be generated in the cities, but the share of these jobs in total regional employment will be higher for the alps and the midlands.

Our results only reflect the time period between 2021 and 2035, since the results of the energy models refer to 2035. They thus only provide a part of the employment impacts of the energy transition that will continue strongly after 2035. Our reference period is characterised by a strong increase in renewable power generation capacities that mainly induces employment for the construction of new power plants and thus temporary jobs that will decline when the period of strong capacity increases is over and when replacement of existing power plants. In the electricity sector, the energy transition is also characterised by a shift of jobs in operation of power plants to jobs in construction of new plants and with suppliers to power plants.

The methodological approach that we have used is flexible in that it can include the available information on the technology-specific supply chains and can be adapted to different data availability situations. When dedicated employment numbers are available for specific technologies, they can be integrated. We have for example included employment factors for nuclear power plants and fuel supply, based on company reports and official statistics. The approach allows to comprehensively cover the whole life cycle of power plants, from construction to dismantling, and the activities in the respective supply chains. Regarding estimates of regional employment, the approach makes use of information on power plant locations. A significant share of regional employment can be derived from this information and the characteristics of the induced economic activities. For the segment of direct suppliers to construction, O&M and dismantling of power plants, some uncertainty remains. Here, a survey of companies active in the energy field and their regional distribution would improve the accuracy of the results. Such a survey was not possible in this project.

Our results only cover a small segment of the energy transition, namely the supply side of electricity generation. Heat generation, mobility and changes on the demand side have not been considered yet. The methodological approach applied in this report can generally also be applied for other parts of the energy transition to estimate their consequences for employment.

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