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*Renewable Energy Valleys to increase energy security while accelerating the green transition in Europe - Innovation action (IA)*



**REFORMERS**  
RENEWABLE ENERGY VALLEYS

**REFORMERS**

Regional Ecosystems **FOR** Multiple-Energy Resilient Systems

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**D3.1: KPI LIST**

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<b>3.1</b>	13.06.2025	Wouter Parys (VUB), Thierry Coosemans (VUB), Gilles Van Kriekinghe (VUB)	Revision after technical review and additional comments
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## EXECUTIVE SUMMARY

D3.1. KPI List defines a list of key performance indicators (KPIs) to quantify/qualify the performance and achievement of the objectives of the flagship valley throughout the project, with respect to technical, environmental impact, economic, and social aspects. In this deliverable, the proposed KPI list will be defined at a holistic and general level so that they serve to adequately quantify the achievement of the objectives of the Flagship Valley (FV). Additionally, Project-level KPIs that apply to the wider impact of REFORMERS have been included.

The possibility of further refinement of these KPIs will be kept until the later stages of the project, depending on the final design, implemented technologies, available data, and FV measurement approach. Besides their relevance, the feasibility of correct measurement and assessment is the criterion for the integration of KPIs in the list. As the project progresses, these KPIs will be further fine-tuned in D3.2 and 4.2, incorporating new information to reflect the FV and the Project's evolving state.

As indicated, the KPIs are divided into four key areas: technical, environmental impact, economic, and social indicators. The technical category focuses on various energy vectors and related technologies, addressing factors such as energy positivity, efficiency, safety, and resilience. Social indicators include end-user comfort, acceptance, ease of use, and inclusivity. The economic category concentrates on revenue creation, operational cost reductions, return on investment, profitability score, and business cases. Environmental impact indicators encompass greenhouse gas emissions and their implications for global warming and air quality, considering a life-cycle perspective.

The comprehensive KPI list will facilitate in-depth analyses of the FV performance during the execution of Work Package 8 (WP8).

In addition, this deliverable also includes KPIs that assess the overall performance of the project since they are closely linked and often overlap with the objectives of the FV. The Project-level KPIs are divided into 3 groups: Dissemination and communication (covering WP2) and wider REFORMERS impact, covering the projected impact of the RV.

Further relevant KPIs for the project deployment related to the different digital tools will be addressed through the relevant deliverables within their own WP: WP5 for the Digital Twin, WP6 for the toolbox covering Energy modelling, Stakeholder engagement, Environmental impact assessment, Business model, governance and policy/legal assessment.

Version 3.1 is a second updated version to address the comments of the Project Officer and external evaluator.



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Acronyms	
<b>BAU</b>	Business as Usual
<b>CA</b>	Consortium Agreement
<b>CAPEX</b>	Capital Expenditure
<b>CEO</b>	Call Expected Outcomes
<b>CO2</b>	Carbon Dioxide
<b>DX.X</b>	Deliverable number X.X
<b>DER</b>	Distributed Energy Resources
<b>EU</b>	European Union
<b>EX</b>	Expenditures
<b>FE</b>	Final energy
<b>FI</b>	Fuel imports
<b>FV</b>	Flagship Valley
<b>GHG</b>	Greenhouse Gas
<b>GWh</b>	Gigawatt-hour
<b>I_GHG</b>	Infrastructure (embodied) GHG emissions
<b>kWh</b>	Kilowatt-hour
<b>KPI</b>	Key Performance Indicators
<b>LCOE</b>	Levelised Cost of Energy
<b>L_GHG</b>	Lifetime greenhouse gas emissions of the project
<b>MWh</b>	Megawatt-hour
<b>MN</b>	Component maintenance
<b>N</b>	Number of years considered for analysis
<b>O_GHG</b>	Total annual greenhouse gas emissions
<b>OPEX</b>	Operational Expenditure



<b>O_PE</b>	Operational primary energy consumption
<b>PC</b>	Project Coordinator
<b>PEF</b>	Primary energy factor
<b>PV</b>	Photovoltaic
<b>REFORMERS</b>	Regional Ecosystems FOR Multiple-Energy Resilient Systems
<b>RE</b>	Renewable Energy
<b>RES</b>	Renewable Energy Sources
<b>REV</b>	Renewable Energy Valley
<b>RV</b>	Replication Valley
<b>SAIDI</b>	System Average Interruption Duration Index
<b>SAIFI</b>	System Average Interruption Frequency Index
<b>SC</b>	Self-consumption
<b>SME</b>	Small and Medium Enterprise
<b>SMEs</b>	Small and Medium-sized Enterprises
<b>SS</b>	Self-sufficiency
<b>T</b>	Time period considered in the assessment of the KPIs, normally 1 year.
<b>EUR</b>	Euro
<b>V</b>	Total amount of energy vectors considered
<b>VUB</b>	Vrije Universiteit Brussel
<b>WPX</b>	Work Package number X
<b>PED</b>	Positive Energy District
<b>SET</b>	Strategic Energy Technology



## 1. INTRODUCTION TO THE FLAGSHIP AND PROJECT OBJECTIVES

In Task 3.1, led by VUB, the REFORMERS Flagship progresses from the initial planning phase to the strategic selection and definition of key performance indicators (KPIs) [M1–M3]. This pivotal task focuses on establishing the overarching objectives for the Flagship's deployment and operational phases. The comprehensive set of objectives encompasses technical, environmental impact, economic, and social categories, as specified in the GA. Furthermore, a detailed KPI list will be crafted, serving as a quantifiable measure for tracking these objectives, using the pre-REFORMERS scenario as a baseline for comparison when required. Also, an annual scope will be defined as the timeframe for calculation when required.

Additionally, Project-level KPIs that apply to the wider impact of REFORMERS have been included. Within the objective of these KPIs lies the projected/expected impact of the Replication Valleys (RV) which share target KPIs with the FV. The calculation of these KPIs in the RV will be calculated or simulated theoretically.

The role of the present D3.1 within REFORMERS is to set the guidelines for the KPIs that will measure and account for the progress, improvements and impacts of the FV of REFORMERS. However, given the still early stage of deployment of the Project, subsequent Tasks and Deliverables will refine the present document: D3.2, The Implementation Plan and D4.2. Implementation and Operation Plan of REVT. Moreover, this Deliverable plays a pivotal role in the project, which can be further understood by analysing its context within the related WP:

### WP3:

- Task 3.2. Current flagship assessment and pathways forward [M1 –M6]: Based on the KPI's from T3.1, the proposed testing and validation methods in T3.2.
- Task 3.4. Data framework, collection, measurement tools and equipment [M3 –M8]: Based on the KPI's from T3.1, the proposed testing and validation methods in T3.2 and the conceptual design in T3.3, Task 3.4 will define the required equipment and tools, providing the backbone for measuring, logging, storing, and monitoring of the technical and socio-economic data links and energy vectors.

### WP5:

- Task 5.1. Digital twin requirements and initial architecture [M1 –M6]: Building upon the results of T3.1 that considers energy valley requirements, T5.1 is focused on the digital realm, and hence, delivers a set of requirements, KPIs and architecture for the digital twin. The results serve as input to T3.4.

### WP8:

- T8.1 Flagship demo assessment and KPI Monitoring, [M8 –M60]: The Flagship demo assessment will be done by getting the input from the KPIs calculation and monitoring done in WP4, to assess the performance from a technical, economic,



environmental, regulatory and social point of view, also taking into consideration the end users (citizens, businesses and others) and critical stakeholders' perception and acceptance of the REFORMERS concept. The performance will be assessed against the impact parameters defined in T3.1, to quantify the real impact of the project concept in the flagship valley, from a replication perspective. A workshop with the most relevant stakeholders of each site at the beginning of the project in collaboration with task 3.1 and 7.1.

The Call Expected Outcomes (CEO) outline the extensive contributions and impacts that REFORMERS aims to achieve. Derived from the Grant Agreement, these CEO encompass quantifiable targets across three categories: scientific, societal (including environmental), and economic/technological aspects. They serve as the foundation for defining the KPIs for both the development of the FV and the broader Project.

#1: Contribute to the implementation of the REPowerEU Plan, specifically by:

1. Maintain a citation rate of at least 5 citations per year per publication for new knowledge on diversifying supply and substituting fossil fuels in hard-to-abate industrial and transport sectors.
2. Achieve a reduction of at least -85% in GHG emissions by 2030 for REFORMERS's FV.
3. Produce 147 GWh/y of biomethane and 259 tons of renewable hydrogen until 2028.
4. Produce 230 GWh/y of biomethane and 3,259 tons of renewable hydrogen until 2030.
5. Eliminate fossil fuel consumption by 100% by 2028.
6. Increase the share of renewable energy by 50% by 2028 and by 119% until 2030.
7. Increase solar photovoltaic - wind capacity by 36% by 2028 and by 149% until 2030.
8. Increase yearly energy savings by 8.5% by 2028 and by 15.6% until 2030, corresponding to a 30 GWh reduction.
9. Energy positivity, elaborated in 3.1.1.1, will increase from 173 to 286% by 2028.<sup>1</sup>

#2: Increase the roll-out of local or regional renewable energy system solutions for electricity, heat, and fuel needs and contribute to their market uptake in Europe.

10. Attain a Likert Scale rating of 4.0/5.0 (High) for the potential of REFORMERS solutions to be scaled and replicated.
11. Involve at least 600 citizens in renewable energy communities or equivalent by the end of REFORMERS.
12. Include a minimum of four end-users (e.g., building, mobility, industry, etc.) in the RE Valley (i.e., buildings, mobility, industry/industrial parks, stadiums).

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<sup>1</sup> The calculation method as defined in this deliverable is altered in comparison with the grant agreement calculation methodology. In the grant agreement a baseline of 100% is used (when total production equals consumption), as in the KPI definition of this deliverable this baseline is set to 0%. The result is that the energy positivity target of 286% will be altered to 186% when following the new KPI definition. However, this is no fundamental change as both numbers have the exact same intrinsic meaning.



13. Ensure economic benefits deriving from the project's implementation exceed €25 million per year.

#3: Create new sustainable jobs linked to local or regional renewable energy system value chains and enhance economic growth in local or regional European communities.

14. Generate 40,000 new jobs by 2030 linked to renewable energy system value chains.

15. Have at least 10,000 interested stakeholders acquire new skills in renewable energy production.

16. Invest over €1.1 billion until 2028 for the creation of the RE valley.

17. Invest an additional €3 billion in RE valley until 2030.

#4: Enhance security and autonomy of local or regional energy supply in EU Member States/Associated countries in current and future climate conditions.

18. Reduce net energy imports (of any type) by 100%, corresponding to over €8.3 million per year.

19. Aim for 35% of the energy produced within the boundaries of the FV valley to be consumed locally on a yearly base.

20. Increase energy storage capacity by 181,738 kWh per year in the FV by the end of the project.

#5: Increase the readiness, reliability, performance, and affordability of local or regional renewable energy system solutions in Europe.

21. Maintain a citation rate of at least 5 citations per year per publication for new knowledge on increasing the reliability, performance, and affordability of renewable energy system solutions.

22. Target final electricity and heating prices (cost to the end-user) at €230/MWh and €100/MWh respectively.

23. Increase electricity and thermal flexibility by at least 15% and 28% respectively.

24. Ensure the majority of installed RE can be 100% utilised to reduce energy curtailment of RES and DER.

25. Maintain System Average Interruption Frequency Index (SAIFI) below 1.5 interruptions/year and System Average Interruption Duration Index (SAIDI) below 2.5 hours/year.

26. Increase the accuracy of RES forecasts by more than 10%.

### **Clarifications added after the first review meeting of 25.04.2025 and additional comments of the project officer and the external reviewer**

- CEO 9: The cited energy positivity target is defined based on the assumptions in the grant agreement. It takes into account the foreseen and forecasted energy innovations and investments. The increase in energy positivity is mainly caused by the expected uptake in solar production and renewable gas production (hydrogen and bio-methane) from biomass. The biomass import streams are considered as bio-waste with a net-zero energy value.



- CEO 13: The cited target of >25million €/y is estimated to be the revenue that results from realization of Europe’s first Renewable Energy Valley in Alkmaar. These (amongst others) cover the sum of:
  - The added revenue of FV partners directly connected to the implementation of the Energy-Innovations
  - The revenues of the business at the harbor that wouldn’t be able to settle at the harbor if it wasn’t for the realization of the Harbor Virtual Local Energy System
  - The (added) revenue of the business located at InVesta that wouldn’t been able to settle if it wasn’t for the realization for the InVesta Virtual Energy System
- CEO 19: The cited target of an annual consumption of 35% of the local production is accordingly and thus based on the, in the grant agreement described, forecasted energy balance towards 202. The local energy production by the biomass plant (heat and electricity production by HVC), the existing and new solar energy, the wind turbines and the planned bio-methane production plants (Engie & SCW Systems) will result in an overproduction and net export of energy for the respective energy carriers by 2028. The total energy demand in 2028 (without biomass import streams) is based on statistic trends (e.g. energy efficiency) and assumptions on the installation of energy innovations (e.g. heat pums). The total yearly demand is estimated to be 35% of the total production.
- CEO 23: The targeted flexibility target increases of 15% and 28% towards 2028 for electricity and heat respectively are based on the assumptions of the grant agreement and combine the expected investments in storage assets and the activation of existing flexible assets. It is assumed that a relative growth of flexible assets will results in a proportionate increase of real available operational flexibility.

With regard to the increase of electric flexibility (by 15%), all flexible (and controllable) electric assets could be considered – such as batteries, cooling installations, compressors, high temperature heat pumps, etc. The increase in electric flexibility is hence calculated by comparing the relative growth (new available flexible capacity compared to the baseline available flexible capacity (kWe).

With regard to the increase in thermal flexibility (by 28%), a similar approach is used by looking at all flexible heat assets (such as the bio-energy plant and heat buffer). The baseline thermal flexibility comprises of i.a. the bio-energy plant (which is flexible in producing heat or power). The total installed flexible capacity (new + old) comprises of i.a. the bio-energy plant (which becomes more flexible in its operation due to addition of the geothermal source) and heat buffer.

## 2. OBJECTIVES AND KPIS DEFINITION

The Call Expected Outcomes (CEO) establish the need for quantifiable and/or qualifiable KPIs that measure the advancement of the Project, both FV and wider impact. Therefore, as a means to facilitate the designation and definition of these KPIs, the original categories included in the CEO are extended and reshaped:



- Technical: Energy system and -device level, covering the different vectors and technologies
- Economic: Revenue and cost change of the main actors
- Social: Community and behavioral change, involvement
- Environmental: Reduction of greenhouse gas emissions and impact on the environment

Furthermore, the Project level KPIs have been categorised according to the wider impacts:

- Dissemination and communication
- Wider REFORMERS impact
- Projected impact from Pilots

Each category has at least one objective. Each objective comprises at least one KPI that will quantify the progress in that area. KPIs will rely on one or more measurements for quantification/qualification purposes. In REFORMERS, all FV objectives and KPIs will be assessed using real measured data from the Flagship case and third-party sources if necessary. A clear definition of applicable KPIs is necessary to define the measurements that will be made and delivered.

The baseline reference for comparison of the KPIs will be the pre-REFORMER’s situation.

## 2.1. Flagship Valley

Table 1 - KPIs related to the REFORMERS’ Flagship Valley

Category	Objective	Relevant KPIs	CEOs cross ref.
Technical	Multi-energy system	Energy positivity	9
		Renewable energy curtailment	24
		Diversification of gas supply	5, 18
		Flexibility	23
	Grid reliability and stability	System average interruption frequency index	25
		System average interruption duration index	25
	Assets and gas production capacity	PV power capacity	6, 7
		Wind power capacity	6, 7
		Storage capacity	20
		Biomethane production capacity	3, 4
Hydrogen production capacity		3, 4	



	<b>Forecasting</b>	Predictability of supply	26*
		Predictability of demand	26*
<b>Social</b>	<b>Engagement representativeness</b>	Variation in types of stakeholders engaged	10, 11, 12, 15
		Participation rate (of various stakeholder groups)	10, 11, 12, 15
		Type of participation	11, 12, 15
	<b>Increased stakeholder acceptance</b>	Compliance with stakeholder objectives	11, 12, 15
		Countering of perceived hurdles for participation	10, 11, 12, 15
	<b>Increased stakeholder expertise</b>	Change in energy (valley) knowhow of users	11, 12, 15
		Impact of education and community events	1, 12, 15
<b>Economic</b>	<b>Affordability</b>	Levelised Cost of Energy (LCOE)	22
		Capital Expenditure (CAPEX)	16, 17
		Operational Expenditure (OPEX)	8, 13
	<b>Viability</b>	Payback period	13
<b>Environmental</b>	<b>Environmental impact</b>	Total direct CO2 emissions	2
		Total GHG footprint (use-stage impacts)	2
	<b>Self-sustainability</b>	Primary energy consumption	18, 19
		Self-sufficiency ratio	18
		Self-consumption ratio	19

\*The forecasting tools have been left out of the scope of the present deliverable as these services will be provided by the Digital Twin in WP5.

## 2.2. REFORMERS whole Project

Table 2 - KPIs related to the REFORMERS project

Category	Objective	Relevant KPIs	CEOs cross ref.
<b>Dissemination and communication (WP2)</b>	<b>Products</b>	Press releases delivered to traditional media	11, 15
		Videos	11, 15
		Webinars	11, 15



		Brochures	11, 15	
		Tech briefs/info packs	11, 15	
		General press/magazine articles published	11, 15	
		News from the project (website + social media)	11, 15	
		Unique website visitors	11, 15	
	<b>Activities</b>	Large public events organised for external audiences	11, 15	
		External events attended representing the project	11, 15	
		Liasing activities with other EU-funded projects	15	
		Workshops organised by the project	11, 15	
	<b>Scientific outreach</b>	Workshop participants	11, 15	
		Number of publications in peer-reviewed journals	1, 21	
	<b>Online presence</b>	Number of publications in peer-reviewed conferences	1, 21	
		Twitter followers	11, 15	
	<b>Gender balance</b>	LinkedIn followers	11, 15	
		Female presenters/keynotes/panelists over total	11, 15	
		Female participants over total	11, 15	
	<b>Wider REFORMERS impacts</b>	<b>Socio-economic</b>	Female respondents over total	11, 15
			Research and industry collaborations	15
Local employment creation			14	
<b>Projected impact on Pilots</b>	<b>Environmental</b>	Number of SMEs involved	12, 15	
		Total direct CO2 emissions (FV + Pilots)	2	
<b>Projected impact on Pilots</b>	<b>Technical</b>	Energy positivity	9	
		<b>Economic</b>	Levelised Cost of Energy (LCOE)	22
	Operational expenditures (OPEX)		8, 13	
	<b>Social</b>	Participant acceptance	10, 11, 12, 15	
		Participation rate (of various user groups)	10, 11, 12, 15	
	<b>Environmental</b>	Total direct CO2 emissions	2	
		Self-sufficiency ratio	18	
Primary energy consumption		18,19		



### 3. FLAGSHIP VALLEY KPIS

#### 3.1. Technical KPIS

##### 3.1.1. Multi-energy vector system integration

###### 3.1.1.1. Energy positivity

Energy positivity refers to the measurement of the FV's ability to generate more energy than it consumes over a specified period. The target aligns with the definition of a Positive Energy District (PED) defined in the European SET Plan (SET Plan Action 3.2). Energy positivity will be used as a KPI to measure the balance between the energy produced and the energy consumed in the FV.

$$EP = 100 \cdot \left( \frac{\sum_{v=1}^V \sum_{t=1}^T (E(t)_{\text{production}}^v - E(t)_{\text{consumption}}^v)}{\sum_{v=1}^V \sum_{t=1}^T E(t)_{\text{consumption}}^v} \right)$$

EP [%] = Energy Positivity of the FV over a year, expressed as a percentage.

$E(t)_{\text{consumption}}^v$  [kWh] = Final energy consumption per time step, t, for a given energy vector, v.

$E(t)_{\text{production}}^v$  [kWh] = Energy production per time step, t, for a given energy vector, v.

V = Total amount of energy vectors considered among electricity, heat, cooling, hydrogen, etc.

T = Time frame considered for the calculation of the Energy Positivity, 1 year.

Note that the energy positivity KPI does only take into account the total volumes of production and consumption over the reference period of one year and does not take into account the synchronicity between production and consumption, hence avoiding to indicate performance monitoring *at all times*, Synchronicity is however reflected in the KPIS *self-sufficiency* and *self-consumption* (described in detail in paragraph: 3.4.2)

###### 3.1.1.2. Renewable energy curtailment

Renewable energy curtailment assesses the amount of renewable energy production that goes unused or is deliberately reduced (controllable producer assets) due to grid constraints or operational limitations. Monitoring renewable energy curtailment helps identify system bottlenecks, optimise grid infrastructure, and improve overall renewable energy utilisation, contributing to energy sustainability goals.

$$RE_{\text{curtailment}} = 100 * \frac{\sum_{a=1}^A \sum_{t=1}^T RE(t)_{\text{curtailed}}^a}{\sum_{a=1}^A \sum_{t=1}^T RE(t)_{\text{produced}}^a}$$



$RE_{\text{curtailment}} [\%]$  = Renewable energy curtailment of the FV over a year, expressed as a percentage.  
 $RE(t)_{\text{curtailed}}^a [\text{kWh}]$  = Renewable energy curtailed in a controllable asset a, at a time step t.  
 $RE(t)_{\text{produced}}^a [\text{kWh}]$  = Renewable energy produced in a controllable asset a, at a time step t.

A = Total amount of controllable producer assets such as PV panels, wind turbines.

T = Time frame considered for the calculation of the RE curtailment, 1 year.

In the case of unavailability of measurements, the curtailment of RES, will be calculated by means of the absolute and relative curtailment:

$$RE_{\text{curtailment}} = 100 * \frac{\sum_{a=1}^A \sum_{t=1}^T (RE(t)_{\text{expected}}^a - RE(t)_{\text{produced}}^a)}{\sum_{a=1}^A \sum_{t=1}^T RE(t)_{\text{expected}}^a}$$

$RE_{\text{curtailment}} [\%]$  = Renewable energy curtailment of the FV over a year, expressed as a percentage.

$RE(t)_{\text{expected}} [\text{kWh}]$  = Calculated energy generated by the asset, a, at a time step, t. The calculation is expected by means of the energy modelling tools by feeding meteorological data,

$RE(t)_{\text{produced}} [\text{kWh}]$  = Renewable energy produced in a controllable asset a, at a time step t.

A = Total amount of controllable producer assets: PV panels, wind turbines.

T = Time frame considered for the calculation of the RE curtailment, 1 year.

### 3.1.1.3. Diversification of gas supply

As part of the strategy to increase the resiliency of the energy system and reduce external dependency, aligned with REPowerEU, the diversification of gas supply and inherent reduction of natural gas consumption is one of the main goals of the FV. The increase in biomethane and renewable hydrogen production will be a key element in addressing this point.

$$DGS = 100 * \left( 1 - \sum_{t=1}^T \left( \frac{C(t)_{\text{natural gas}}}{\sum_{g=1}^G C(t)_g} \right) \right)$$

DGS [%] = Diversification of Gas Supply, as a function of the reduction of the Natural Gas usage share.

$C(t)_{\text{natural gas}} [\text{kWh}]$  = Natural gas consumption per time step, t.

$C(t)_g [\text{kWh}]$  = Consumption of a gas, g, over a time step, t.

T = Time frame considered for the calculation of the Diversification of gas supply, 1 year.



### 3.1.1.4. Flexibility<sup>2</sup>

The project aims to measure how much additional flexible capacity is installed or activated, both on demand and generation side. The higher the installed flexible capacity, the better renewable energy systems can be integrated taking into account production volatility, grid conditions, demand fluctuations and market dynamics. We propose using the following formulations to assess both upward (solution for local energy deficit or limited available grid offtake capacity) and downward (solution for local energy surplus or limited available grid injection capacity) flexibility.

Upward flexibility is defined by:

$$FLEX_v^{up} = 100 * \left( \frac{\sum_{t=1}^T C_{flex\_up}(t)_v^{generation} + \sum_{t=1}^T C_{flex\_down}(t)_v^{demand}}{\sum_{t=1}^T C_{tot}(t)_v^{demand}} \right)$$

$FLEX_v^{up}$  [%] = Measure for instantaneous increase in production and decrease in consumption potential. It is defined as the weighted average of the sum of available upward flexibility for generation and downward flexibility for demand divided by the sum of the demand, for an energy vector, v.

$C_{flex\_up}(t)_v^{generation}$  [kWh] = energy volume that represents the available upward (potential increase in production) flexible production capacity at timestep t, defined by the integral over timestep t, for an energy vector v.

$C_{flex\_down}(t)_v^{demand}$  [kWh] = energy volume that represents the available downward (potential decrease in consumption) flexible consumption capacity at timestep t, defined by the integral over timestep t, for an energy vector v.

$C_{tot}(t)_v^{demand}$  [kWh] = energy volume that represents the total consumption capacity at timestep t, defined by the integral over timestep t, for an energy vector v.

T = Time frame considered for the calculation of the Flexibility: 1 year.

Downward flexibility is defined by:

<sup>2</sup> The proposed KPI calculation method is altered and refined in between v3.0 and v3.1 of this document based on the reviewers comments. The initial KPI is split up in a separated upward and downward component and the focus is shifted towards available flexible capacity at each timestep instead of counting the total shifted energy volumes. The advantage is that this KPI definition represents better the local state of the energy system, as well the measurability is increased.



$$FLEX_v^{down} = 100 * \left( \frac{\sum_{t=1}^T C_{flex\_down}(t)_v^{generation} + \sum_{t=1}^T C_{flex\_up}(t)_v^{demand}}{\sum_{t=1}^T C_{tot}(t)_v^{demand}} \right)$$

$FLEX_v^{up}$  [%] = Measure for instantaneous decrease in production and increase in consumption potential. It is defined as the weighted average of the sum of available downward flexibility for generation and upward flexibility for demand divided by the sum of the demand, for an energy vector, v.

$C_{flex\_down}(t)_v^{generation}$  [kWh] = energy volume that represents the available downward (potential decrease in production) flexible production capacity, at timestep t, defined by the integral over timestep t, for an energy vector v.

$C_{flex\_up}(t)_v^{demand}$  [kWh] = energy volume that represents the available upward (potential increase in consumption) flexible consumption capacity, at timestep t, defined by the integral over timestep t, for an energy vector v.

$C_{tot}(t)_v^{demand}$  [kWh] = energy volume that represents the total consumption capacity at timestep t, defined by the integral over timestep t, for an energy vector v.

T = Time frame considered for the calculation of the Flexibility: 1 year.

Note that the upper limit of this KPI (both upward and downward) is not bounded by a theoretically max of 100% as demand flexibility and generation flexibility are summed together and upwards flexibility is mathematically not limited in any case.

This KPI reflects the potential to react on instantaneous requests of both upward and downward flexibility.

### 3.1.2. Grid reliability and stability

#### 3.1.2.1. System average interruption frequency index

The System Average Interruption Frequency Index (SAIFI) measures the average number of interruptions that a customer experiences within a specified time frame, typically per year. To elaborate on this KPI:

$$SAIFI = (\text{Total number of customer interruptions}) / (\text{Total number of customers})$$

#### 3.1.2.2. System average interruption duration index

The System Average Interruption Duration Index (SAIDI) measures the average duration of interruptions experienced by customers within a specified time frame, usually per year. To elaborate on this KPI:

$$SAIDI = (\text{Total duration of interruptions}) / (\text{Total number of customers})$$



### 3.1.3. Assets and gas production capacity

In order to measure the achievement of the deployment goals and production targets. The following KPIs are to be measured:

- PV power capacity [kWp]
- Wind power capacity [kW]
- Storage capacity per vector [kWh/y]
- Biomethane production capacity [GWh/y]
- Hydrogen production capacity [GWh/y]

## 3.2. Social KPIs

### 3.2.1. Engagement representativeness

#### 3.2.1.1. Variation in types of stakeholders engaged

An energy valley is an ecosystem that requires the active participation of various types of stakeholders in its design as well as its deployment phase. Following the quadruple helix model, 4 main types of stakeholders can be identified: governments, industry, social organizations and citizens, and academia. The variation in stakeholders that cooperate in engagement efforts will be identified through an analysis of the helix-types that are represented, as well as of the percentage of participants that represent each of these stakeholder types.

#### 3.2.1.2. Participation rate (of various stakeholder groups)

The participation rate represents the success rate of invitations to stakeholder engagement activities for different stakeholder types. It will be calculated as follows:

Participation\_rate (per stakeholder type) =

$$\text{Number\_of\_Engaged\_Stakeholders} / \text{Invited\_Number\_of\_Stakeholders}$$

#### 3.2.1.3. Type of participation

To create an insight into the intensity of the engagement initiatives and their potential impact, an overview will be kept of the number and % of stakeholders that are actively engaged in the project versus the ones that are passively engaged. 'Active engagement' is defined as the opportunity for direct participation various project aspects, and regular interaction and communication between the stakeholders and the project leaders; 'passive engagement' is defined as being informed or consulted about the project without necessarily having a direct role in shaping its outcomes or processes.

The goal will be to ensure a balance between actively and passively engaged stakeholders.



### 3.2.2. Increased stakeholder acceptance

#### 3.2.2.1. Compliance with stakeholder objectives

At the start of the project, a survey will be sent out to all relevant stakeholders, with the goal of identifying their main objectives when joining an energy valley initiative. The evaluation of the alignment between the project's final outcomes and the stakeholder objectives will hinge on the findings from a subsequent survey. This second survey, directed at the same stakeholders as the initial survey, will explicitly inquire about the achievement of the objectives they identified earlier, and incentives will be used to recruit the same stakeholders as during the first survey. Additionally, a theoretical desktop analysis of how the identified main objectives are specifically integrated in the project outcome will be conducted. In case the participation rate in the post-survey is low, this desktop analysis will be the main qualitative assessment method for this KPI.

#### 3.2.2.2. Countering of perceived hurdles for participation

At the start of the project a survey will be sent out to all relevant stakeholders, to identify what they perceive as the main hurdles to joining an energy valley initiative. The assessment of how solutions to address these barriers are incorporated into the project's final outcomes will rely on the findings of a follow-up survey. This second survey, distributed to the same stakeholders as the initial survey, will specifically inquire about the extent to which the project results offer tools to overcome the hurdles previously identified by the stakeholders. Additionally, a theoretical analysis of how the identified main hurdles are specifically integrated in the project outcome will be conducted. In case the participation rate to the post-survey is low, this desktop analysis will be the main assessment method for this KPI.

### 3.2.3. Increased stakeholder expertise

#### 3.2.3.1. Change in energy (valley) knowhow of users

At the end of the project, a self-assessment survey will be developed per stakeholder type. This survey will include inquiries regarding the stakeholders' perceived enhancements in knowledge acquired during their engagement in the project. The topic or the concrete questions will depend on what will be identified as essential user skills and knowledge throughout the course of the project for each stakeholder group (e.g. business model knowledge or understanding of necessary governance structures).

#### 3.2.3.2. Impact of education and community events



In stakeholder events aimed specifically at providing information or education on a specific energy (valley) topic, an assessment/self-test will be incorporated. This assessment will include questions related to the focal topic, enabling the evaluation and analysis of any shifts in the participants' knowledge and/or skills resulting from the event. The format of the assessment will be tailored to the subject and setup of the event (e.g. employing a pre- and post-(group) quiz or a concise evaluation survey).

### 3.3. Economic KPIs

#### 3.3.1. Affordability

##### 3.3.1.1. Levelised Cost Of Energy (LCOE)

The Levelised Cost Of Energy (LCOE) is a life-cycle indicator of the cost of producing or consuming a certain energy vector. It measures the lifetime costs of a certain amount of energy. The LCOE calculation can be performed at different points of an energy system, f.e. production point vs. consumption point. Each point provides insights into different aspects of the system's economics and efficiency. Furthermore, in Multi-Energy Systems, the calculation of the LCOE must account for not only the costs associated with each energy vector and their respective production technologies but also the different balances and respective distribution pathways of each vector.

$$LCOE^v = \frac{\sum_{y=1}^L \sum_{s=1}^S \sum_{t=1}^T \frac{EX^{v,s}}{(1+i)^y}}{\sum_{y=1}^L \sum_{s=1}^S \sum_{t=1}^T \frac{E(t)_{consumption}^{v,s}}{(1+i)^y}}$$

$LCOE^v$  [EUR/kWh] = Levelised Cost Of Energy of vector, v, at the consumption point.

$EX^{v,s}$  [EUR] = Expenditures from consumption of the vector, v, from the source, s.

$E(t)_{consumption}^{v,s}$  [kWh] = Energy consumption of the vector, v, from the source s.

$i$  [%] = Discount rate

$y$  [year] = Year within the lifetime, L, of the system/project

$T$  = Total number of time steps within a year, for a given time step granularity, t.

$S$  = Total amount of sources supplying the vector, v, at the point of consumption measuring the LCOE.

##### 3.3.1.2. Capital Expenditures (CAPEX)

Capital Expenditure (Capex) is indicating the value an entity has spent on purchases of property and equipment. These purchases are considered as investment flows to expand or



improve existing assets. All capital expenditures must be listed and totalized. Capex is measured in €.

### 3.3.1.3. Operational Expenditures (OPEX)

Operating Expenditures (Opex) are the expenses required to maintain and operate existing assets. All Opex must be listed and totalized. One of the goals the efficiency of minimising expenses associated with the operation and maintenance of renewable energy infrastructure. It focuses on optimising processes, technology utilisation, and resource management to drive down operational expenditures while advancing sustainable energy goals. Opex is measured in €.

## 3.3.2. Viability

### 3.3.2.1. Payback period

The payback time is the period required for the cumulative financial returns from an investment to equal the initial capital outlay, indicating the efficiency of the investment. It is measured in [years], it can be calculated using the following formula:

$$\text{Payback time [years]} = \frac{\text{CAPEX}}{\text{TYC}_{\text{reduction}}}$$

CAPEX = Capital Expenditures [€]

TYC<sub>reduction</sub> = Total Yearly Cost reduction compared to the reference scenario BAU [€/year]

## 3.4. Environmental KPIs

### 3.4.1. Environmental impact

#### 3.4.1.1. Total direct CO<sub>2</sub> emissions

This KPI refers to the annual CO<sub>2</sub> emissions incurred as a result of the FV's operation. Operational CO<sub>2</sub> emissions are incurred during the use-phase of the components and are calculated as the sum of the emissions incurred due to component maintenance and the emissions incurred due to component fuel consumption. In this KPI, "fuel" refers to both fossil fuels and electricity consumed by the building's components, as applicable. Moreover, the KPI includes embodied emissions due to component replacements. The calculation does not take into account emissions offset due to RES production and the KPI is calculated on a per-building basis. For district-level analysis, the corresponding calculation is the sum of the values calculated for each individual building. Although the KPI is calculated as an aggregate, the values per energy vector can be reported as well.



The total operational CO2 emissions of the FV are calculated as the sum of the alley's GHG emissions over an analysis period. The granularity and dimensions of the output depend on the scope of the analysis (e.g. project-level, annual, monthly, etc). For the indicative example of calculations of a total sum calculated on an annual basis and an analysis period of N years, the corresponding calculations are as follows:

$$O_{GHG} = \sum_{i=1}^N (O_{GHG,MN}^{(i)} + O_{GHG,FI}^{(i)})$$

$O_{GHG,MN}^{(i)}$  are the annual emissions incurred due to component maintenance in year  $i$ ;

$O_{GHG,FI}^{(i)}$  are the emissions due to energy consumed by the (electrical or fuel) in year  $i$ .

The annual emissions due to component maintenance are calculated as the sum of emissions for all components, as provided by manufacturers and/or contractors:

$$O_{GHG,MN}^{(i)} = \sum_{\forall j \in Components} O_{GHG,MN,j}^{(i)}$$

$O_{GHG,MN}^{(i)}$  are the annual GHG emissions required for the maintenance of component  $j$  in year  $i$ .

### 3.4.1.2. Total CO2 footprint (use-stage impacts)

This KPI indicates the total GHG emitted during the analysis' lifetime. This total consists of the infrastructure (Embodied) GHG emissions and of Operational & Maintenance (Use stage). Specifically, the Use Stage includes maintenance-related GHG emissions (Use / Maintenance / Repair / Replacement (inc. end of life of components) / Refurbishment) and Operational emissions (due to energy consumed as electricity or fuel). Finally, Building-level End-of-Life emissions are not considered in this KPI. The GHG emissions over the lifetime of the entire project (assumed to be N years) is calculated as the sum of the infrastructure (product / construction) emissions and use-stage emissions over the period of estimation.

$$L_{GHG} = I_{GHG} + \sum_{i=1}^N (O_{GHG}^{(i)})$$

$L_{GHG}$  is the Lifetime GHG Emissions of the Project;

$I_{GHG}$  is the Infrastructure (embodied) GHG Emissions;

$O_{GHG}^{(i)}$  is the Operational GHG emissions of the building's components in year  $i$ .

The Infrastructure (embodied) GHG emissions, which are incurred only when components are installed at the beginning of a project and are not included in the calculation of this KPI for pre-existing components, are defined as:



$$I_{GHG} = \sum_{\forall j \in Components} I_{GHG,j}$$

$I_{GHG,j}$  are the GHG Emissions embodied in component  $j$ .

The Total Operational annual GHG emissions are defined as:

$$O_{GHG}^{(i)} = O_{GHG,MN}^{(i)} + O_{GHG,FI}^{(i)} - O_{GHG,PR}^{(i)}$$

These three terms are further elaborated in the subsequent bullet points:

Annual emissions due to component maintenance,  $O_{GHG,MN}^{(i)}$ :

$$O_{GHG,MN}^{(i)} = \sum_{\forall j \in Components} O_{GHG,MN,j}^{(i)}$$

$O_{GHG,MN,j}^{(i)}$  are the annual GHG emissions required for the maintenance of component  $j$  in year  $i$ .

Emissions generated due to fuel imports,  $O_{GHG,FI}^{(i)}$ :

$$O_{GHG,FI}^{(i)} = \sum_{\forall k \in Fuel\ Types} FI_k^{(i)} \cdot EF_k^{(i)}$$

$FI_k^{(i)}$  is the total Fuel Imports for fuel type  $k$  in year  $i$ , obtained from energy demand timeseries (in kWh);

$EF_k^{(i)}$  is the GHG emission factor associated with fuel type  $k$  (this can differ depending on the project country and the energy mix) in year  $i$ .

Emissions avoided due to RES production,  $O_{GHG,PR}^{(i)}$ :

$$O_{GHG,PR}^{(i)} = (SC^{(i)} + EX^{(i)}) \cdot EF_{el}^{(i)}$$

$SC^{(i)}$  and  $EX^{(i)}$  are respectively the total RES energy that was self-consumed and exported by the building in year  $i$ .

$EF_{el}^{(i)}$  is the GHG emission factor associated with fuel type  $k$  (this can differ depending on the project country and the energy mix) in year  $i$ .

### 3.4.2. Self-sustainability

#### 3.4.2.1. Primary energy consumption



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Research and Innovation SERI

Swiss Confederation

This KPI indicates the total primary energy (PE) consumption during the analysis' lifetime. This total consists of the Infrastructure (Product / Construction stages) that incurred the first time a component is installed) and of Operational & Maintenance (Use stage) that incurred during the use-phase and includes maintenance PE demand (Use / Maintenance / Repair / Replacement (inc. EoL of components) / Refurbishment) and operational PE consumption (energy consumed as electricity or fuel). Moreover, End-of-Life of Building lifecycle is not considered in this KPI.

$$L_{PE} = I_{PE} + \sum_{i=1}^N (O_{PE}^{(i)})$$

$L_{PE}$  is the Lifetime PE consumption of the Project;

$I_{PE}$  is the Infrastructure (embodied) PE consumption;

$O_{PE}^{(i)}$  is the Operational PE demand of the building's components in year  $i$ .

The Infrastructure (embodied) PE consumption is defined as:

$$I_{PE} = \sum_{\forall j \in Components} I_{PE,j}$$

$I_{PE,j}$  is the PE embodied in component  $j$ .

When calculated on the basis of component consumption, the Operational PE consumption is defined as:

$$O_{PE}^{(i)} = \sum_{\forall j \in Components} FE_j^{(i)} \cdot PEF_{fuel,j} + O_{PE,MN,j}^{(i)}$$

$FE_j^{(i)}$  is the Final Energy consumed by component  $j$  in year  $i$ , obtained from energy consumption timeseries;

$PEF_{fuel,j}^{(i)}$  is the PE factor associated with the fuel consumed by component  $j$  (this can differ depending on the project country and the energy mix), for year  $i$ ;

$O_{PE,MN,j}^{(i)}$  is the maintenance PE demand (inc. replacement & EoL) of component  $j$  for year  $i$ .

Unless explicit values are provided, maintenance PE demand is calculated as a percentage of a component's embodied PE, while EoL PE demand depends on the scheduled fate of the component at the end of its useful lifetime. If a component's life ends during the analysis' lifetime and has been scheduled to be replaced, the corresponding embodied PE demand is added to that component's Operational PE Demand for that year.

### 3.4.2.2. Self-sufficiency ratio

The ability of a system to meet its energy requirements independently, without relying extensively on external energy sources, is defined as the ratio between the total energy produced locally that is directly consumed (energy injected into the grid is not counted) and the total consumption over a year:

$$SS = 100 * \frac{\sum_{v=1}^V \sum_{t=1}^T (E(t)^v_{consumption} - E(t)^v_{net imports})}{\sum_{v=1}^V \sum_{t=1}^T E(t)^v_{consumption}}$$

SS [%] = Self-sufficiency of the FV over a year, expressed as a percentage.

$E(t)^v_{consumption}$  [kWh] = Energy consumption (demand + storage) of an energy vector, v, over a time step, t.

$E(t)^v_{net imports}$  [kWh] = Net imported energy of an energy vector, v, at a time step t.

= Total amount of energy vectors considered, electricity, heat, cooling, hydrogen, etc.

T = Time frame considered for the calculation of the Self-sufficiency, 1 year.

Values of self-sufficiency can vary between 0 and 100%. Since net imported energy cannot exceed the energy consumption (defined as demand + storage), the numerator in the formula cannot be negative. When all consumed energy at all timesteps is imported (none being locally produced), self-sufficiency is 0%. If none of the consumed energy is imported (all being locally produced), self-sufficiency is 100%.

Refinement on the inclusion of energy vectors and the energy conversion values to kWh for all energy vectors is expected in future deliverables.

### 3.4.2.3. Self-consumption

Self-consumption refers to the percentage of the total local produced energy that is actually consumed locally at all times. The part of the production that is consumed on-site equals the total production volume minus the net energy exported at each point in time. The KPI is evaluated over a year through a weighted average.

$$SC = 100 * \frac{\sum_{v=1}^V \sum_{t=1}^T (E(t)^v_{produced on-site} - E(t)^v_{net exports})}{\sum_{v=1}^V \sum_{t=1}^T E(t)^v_{produced on-site}}$$

SC[%] = Self-consumption of the FV over a year, expressed as a percentage.

$E(t)^v_{produced on-site}$  [kWh] = Locally produced energy of an energy vector, v, at a time step, t.



$E(t)_{net\ exports}^v$ [kWh]= Exported energy of an energy vector, v, at a time step t.

V = Total amount of energy vectors considered, electricity, heat, cooling, hydrogen, etc.

T = Time frame considered for the calculation of the Self-consumption, 1 year.

Values of this parameter vary between 0 and 100%. Since the net exported energy cannot exceed the energy production at any point in time), the numerator in the formula is always positive. When all locally produced energy is exported at all timesteps (not being locally consumed), self-consumption will be 0%. If none of the locally produced energy is exported (all being locally consumed), the self-consumption will be 100%.

Refinement on the inclusion of energy vectors and the energy conversion values to kWh for all energy vectors is expected in future deliverables.

**Additional clarifications on energetic KPIs after technical review:<sup>3</sup>**

As a background for the energetic KPIs, Figure 1 shows the estimated total production and consumption towards 2028. These numbers result directly in CEO 9 (186% energy positivity towards 2028) and CEO 19 (35% of the production volume will be covered by local consumption volumes). Both are calculated on an annual base.

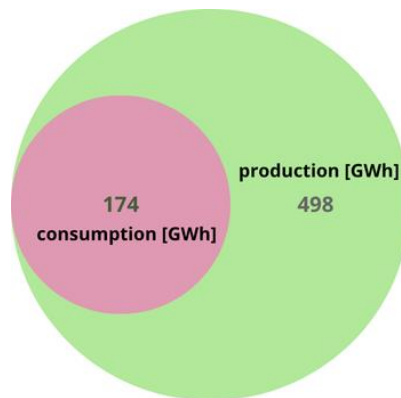


Figure 1: Annual sum for consumption and production in the flagship valley

When time-of-use is taken into account (see Figure 2), the consumption has to be synchronized with the local production to have a positivity impact. The portion of the total consumed energy [estimated at 174 GWh] that is produced and used locally [estimated at 130 GWh] at the same time is defined as the self-sufficiency KPI. The self-sufficiency KPI definition is described in paragraph 3.4.2.2 of this document. The definition of the self-consumption KPI is similar but relates to the direct consumed local production [estimated at 130 GWh] to the total production volume [estimated at 498 GWh]. The self-consumption KPI definition is described in detail in paragraph 3.4.2.3.

<sup>3</sup> Paragraph added partially in v3.0 but adapted and refined in v3.1 of this document. The paragraph is added to give more insights in the terms energy positivity, self-sufficiency and self-consumption.

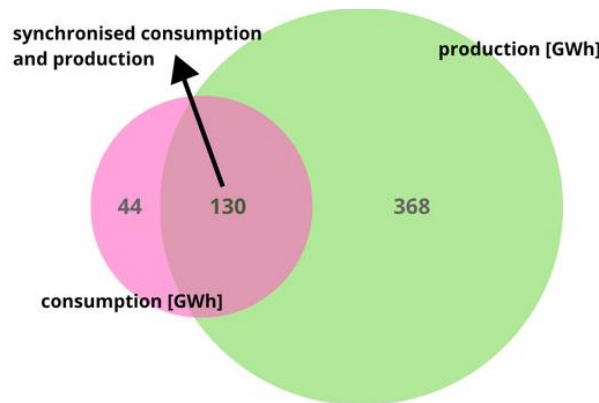


Figure 2: Energy balance (production & consumption) considering time of use.

Better coordination in between consumption and production profiles (by flexibility and storage) would result in higher scores for the KPIs of self-consumption and self-sufficiency. Scores for energy positivity (objective 9) and annual consumption coverage (objective 19) will not be affected by flexibility or storage. They will only be affected due to a change in total consumption and/or production volumes.

## 4. REFORMERS PROJECT KPIS

### 4.1. Dissemination and communication

#### 4.1.1. Products

Various dissemination products will be developed to provide visibility to the project. A count of the final amount of produced products per type will be compared to the set target amount (indicated between brackets).

- Press releases delivered to traditional media [24]
- Published videos (e.g. on YouTube, Vimeo) [1]
- Webinars [3]
- Laid out media (e.g. brochures) [1]
- Tech briefs/info packs [2]
- News items published on the project (e.g. project website and social media) [60]

The effectiveness of the dissemination will be assessed through a count of the number of unique website visitors, with 3000 as a target number.

#### 4.1.2. Activities

Various activities will be organised to make the project known to the general public, as well as to provide participation opportunities to the project stakeholders. A count of the final amount of produced activities per type will be compared to the set target amount (indicated between brackets).



- Large public events organised for external audiences [5]
- External events attended representing the project [10 participating partners]
- Liasing activities with other EU-funded projects [2]
- Workshops organised by the project [24]

The dissemination success of the workshops will be assessed through a count of the amount of participants, with 400 as a target number.

#### 4.1.3. Scientific outreach

The scientific outreach will be measured through a count of scientific publications per type (with the target amount indicated between brackets).

- Publications in peer-reviewed journals [7]
- Publications in peer-reviewed conferences [10]

#### 4.1.4. Online presence

The impact of the online presence will be assessed through a count of the amount of Instagram followers, with 200 as a target number, and the amount of LinkedIn followers, with 500 as a target number.

#### 4.1.5. Gender balance

To determine whether the envisioned gender balance is reached, the representation of women in various activities will be monitored. The target is to have a 50% representation rate in the following cases:

- Female presenters/keynotes/panelists over total
- Female participants over total
- Female respondents to surveys over total

## 4.2. Wider REFORMERS impact

### 4.2.1. Socio-economic impacts

#### 4.2.1.1. Research and industry collaborations

The collaborative efforts between academic and industrial partners regarding R&D activities within the scope of the REFORMERS project will be counted. It encompasses the number of joint ventures, research stays, partnerships, and initiatives established to advance research and development (R&D) activities aligned with the project's objectives.

#### 4.2.1.2. Local employment creation

Number of jobs that have been created as a result of the activities connected to the flagship valley development in Alkmaar. This will be evaluated by checking with the involved partners.



#### 4.2.1.3. Number of SME involved

The number of small and medium-sized companies involved in the project will be counted and followed throughout the project, that means companies that have business related to the project activities and the development of the flagship. A survey including questions regarding what type of sector the companies are connected to will be circulated amongst the partners.

### 4.2.2. Environmental impact

#### 4.2.2.1. Total direct CO2 emissions

Comprising Flagship Valley and Pilots direct CO2 emissions reduction.

### 4.3. Projected impact on pilots

The calculation of the projected impact on RV will be achieved by means of the energy modelling tools developed within the scope of WP6. The definition and formulation of these KPIs is aligned with those included in the FV's KPIs. Hence, have already been described.

- Energy positivity
- Self-sufficiency ratio
- Primary energy consumption
- Levelised Cost of Energy (LCOE)
- Operational expenditures (OPEX)
- Participant acceptance
- Participation rate (of various user groups)
- Total direct CO2 emissions
- Renewable energy penetration

