DELIVERABLE

Acronym / Number	**WASTE2GRIDS / 826161**
Title	Converting WASTE to offer flexible GRID balancing Services with highly-integrated, efficient solid-oxide plants
Duration	18 months
Start date	01.01.2019

Deliverable Number	D1.1
Deliverable Name	Future multi-scale RES-dominated zones and grid-balancing needs
Lead beneficiary	ENEA
Authors (beneficiary)	Alessandro Agostini, Claudio Carbone (ENEA)
Type (R/DEC/...)	R
Disse. level (PU/CO/CI)	PU
Delivery date expected	31.09.2019 (M9)
Actual delivery date	31.10.2019 (M10)
Comments	

Summary

The WASTE2GRIDS project seeks to identify the most promising pathways for waste gasification and reversible solid-oxide cell integrated power balancing plants, with solutions for industry as well as business realization. This report, delivered by ENEA, builds on the outcomes of WT 1.1 (the power-grid balancing needs) and WT 1.2 (waste availability maps) to identify the most favorable zones and estimate the maximum capacity of the W2G plant potential deployment.

For each zone identified the potential waste availability identified in D1.2 is matched, via conservative processing performances provided by WT2.2, with the related RES-dominated zone power balancing needs identified in D1.1.

The outcome of task 1.3 is the identification of the zones with enough wastes and residues availability to support the W2G plants for satisfying significantly the grid-balancing needs and the definition of the maximum capacity of the rSOC both in power storage mode and in power generation mode for a set of potential system designs.

These results will be fed into WT2.3 for assessing and identifying the optimal plant operation, sizing and scheduling based on the techno-economic performances of the systems.

Table of Contents

Acronyms

D	Deliverable
PV	Photovoltaic
RES	Renewable Energy Source
rSOC	Reversible Solid-Oxide Cell
SOEC	Solid-Oxide Electrolysis Cell
SOFC	Solid-Oxide Fuel Cell
TSO	Transmission System Operator
VRESs	Variable Renewable Energy Sources
WP	Work Package
WT	Work Task

1. Introduction

1.1 Background and task description

The overall objective of the WASTE2GRIDS project is to identify the most promising pathways of industrial and business realization for waste gasification and solid-oxide cell integrated power balancing plants.

The project aims are to perform a preliminary investigation on the long-term techno-economic feasibility of waste-based power-balancing plants, to identify several promising business cases and to study the feasibility of large-scale centralized application with the necessary preconditions.

To achieve the overall objective, a first task (WT1.1) was to identify RES-dominated power generation zones and quantify the balancing needs of the power grid. The results of the analysis are reported in D1.1, which is a fundamental input to this deliverable.

In a second task (WT1.2) the availability of waste and residues were quantified for the RES dominated regions identified in D1.1. The zones identified as in need of a non-negligible balancing of the power grid because of the excess power from non-dispatchable renewables are DK1 (Denmark west), DK2 (Denmark east), the Bornholm island and Italy south (SUD).

The scope of the task is to match the balancing needs and the waste availability in the selected RES dominated areas to explore the maximum potential capacities of the W2G plant both in power storage mode and power generation mode.

The concept and design of the W2G plants have been investigated in D2.1 in detail. The W2G plant is operating under three modes: power generation (PowGen) mode, power storage (PowSto) mode and power neutral (PowNeu) mode. The PowGen and PowSto modes are expected to be the dominating operating modes. In PowSto mode, the W2G plant uses excess power from non-dispatchable renewables combined with syngas from waste gasification to produce methane to be injected in the natural gas grid for storage. In PowGen mode, the syngas produced from waste is combusted to produce power.

In this deliverable, we identify neither the optimal scale of the W2G plant nor the optimal operational pattern of the rSOC (i.e. the share the rSOC is operated in power storage or power generation) as this is related to the techno-economics of the technology. It only roughly estimates the total deployment potential for an area or region identified based on D1.1 and D1.2.

1.2 Deliverable structure

The document has been divided into different chapters to present the results of the different steps taken to identify the potential deployment of the W2G plant.

- Section 2 provides an overview of the methodology adopted to quantify the maximum potential deployment.
- Section 3 presents the results of the analysis.
- Section 4 draws the conclusions on the grounds of the results presented in this deliverable.

1.3 Scope and utilization of this report

The scope of this report is to identify the maximum potential deployment of the W2G plant based on the future availability of wastes and residues and the expected balancing needs of the power system due to the higher penetration of renewables in 2030.

The maximum potentials identified are not meant to represent the optimal solution, but rather to set a constraint to the maximum deployment of the technology and support the identification of the optimal design and sizing of the technology. The document cannot be used alone as a reference for decisions and rationales; such decisive implication falls beyond the scope of the document.

2. Materials and methods

In D1.1 four RES (Renewable Energy Sources)-dominated zones were identified, three in Denmark (DK1, DK2, Bornholm) and one in Italy (SUD). For these areas, the balancing need of 2018 was quantified and projection to 2030 was made based on current trends, policies, and targets.

The results are presented as histograms (see Fig.1 for example), showing the frequency and capacity of hourly balancing needs for the power grid system analysis in 2030.

The methodology and results of the assessment of the power balancing needs in the RES-dominated zones can be found in D1.1.

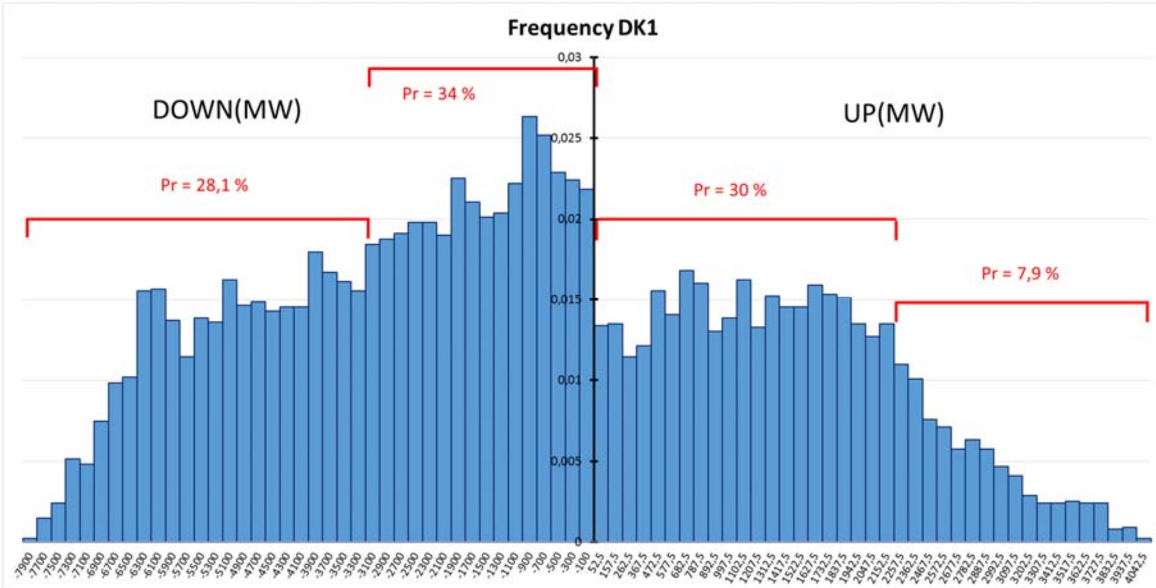

Figure 1 Frequency histogram of the hourly UP/DOWN power capacity in DK1 in 2030. The UP corresponds to the PowGen mode of the W2G plant, while the DOWN corresponds to the PowSto mode of the W2G plant.

In D1.2 the waste and residues availability for the same areas are identified for 2 scenarios:

1) **The technical potential:** the absolute maximum amount of waste and residues potentially available for energy use assuming the absolute minimum of technical constraints and the absolute minimum constraints by competing uses. This potential is provided to illustrate the maximum that would be available without consideration of sustainability constraints.
2) **The base potential:** it includes agreed sustainability standards for agricultural forestry and land management deriving from CAP (Common Agricultural Policy) for agricultural farming practices; land management and agreed (national and regional) forestry management plans for the forestry sector. This also includes the consideration of legal restrictions such as restrictions from management plans in protected areas and sustainability restrictions from current legislation. Further restrictions resulting from RED (Renewable Energy Directive) and CAP are considered as restrictions in the base potential as well. CAP sustainable agricultural farming practices include applying conservation of Soil Organic Carbon (SOC) practices (e.g. Cross Compliance issues of 'maintaining agricultural land in good farming and management condition' and avoiding soil erosion).

The base potential is thus considered as sustainable technical potential. It does not include any economic aspect, in particular regarding alternative uses of the same feedstocks within a future European bio-economy. While this methodological choice tends to overestimate the availability of waste and residues, limiting the waste and supply area to the region under analysis has an opposite impact on the estimates. Residues (and waste in particular) are often transported for long distances, e.g. a large percentage of the waste produced in the Central and Southern regions of Italy are treated in plants located in the Northern regions, indicating a national movement of waste from South to North (Malinauskaite et al., 2017).

Transboundary transport is rather common as well, (EUROSTAT, n.d.), in extraordinary cases also large amounts are transported between countries (NYT, n.d.).

For the scope of this work, we use the BASE potential to account at least for the current sustainability constraints, refraining from any economic analysis of the future competition with other uses.

The methodology for the assessment of the waste and residues availability is reported in D1.2., where detailed georeferenced maps were developed (see Fig. 2).

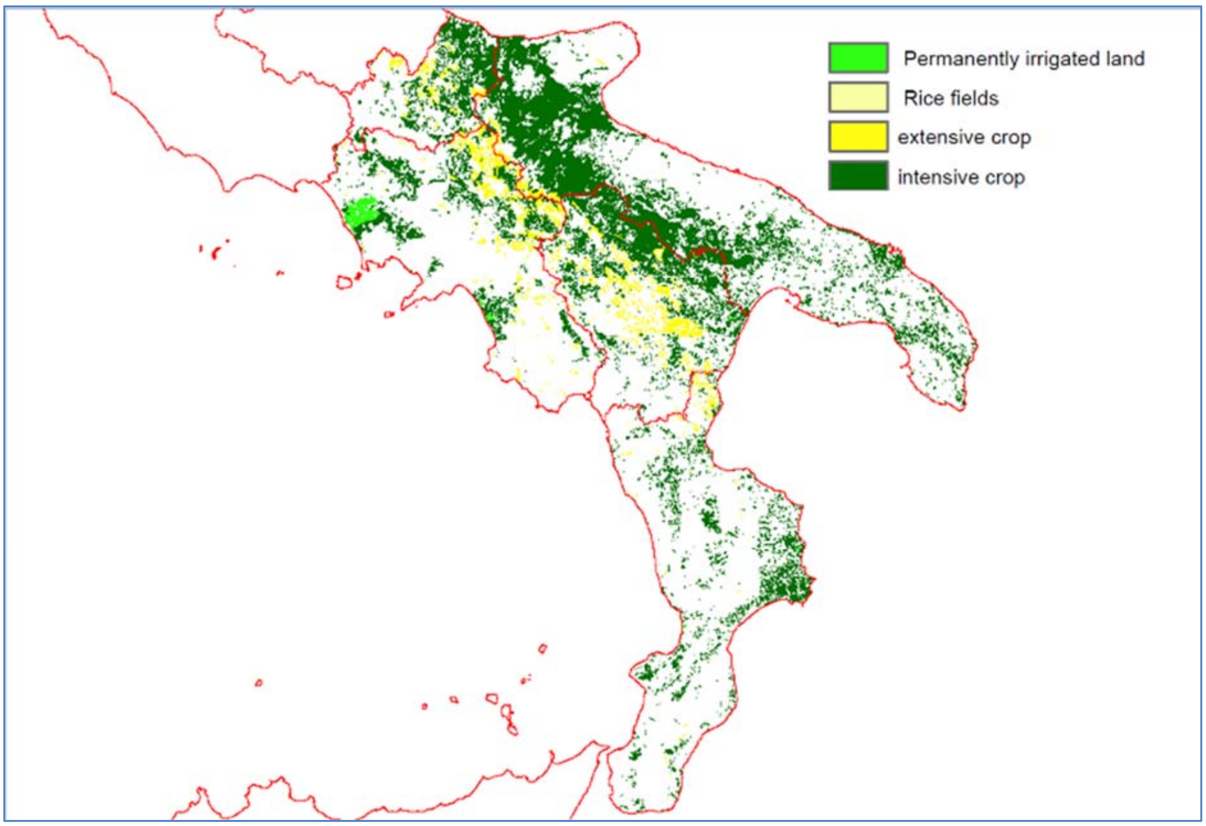

Figure 2 crop cultivation in Italy SUD, the basis for the assessment of straw availability.

D1.2 has provided the total amount of residues and waste (see Tab.1 for Denmark) for each RES-dominated zone identified.

Table 1 Waste and residues availability in Denmark in 2030 [source S2BIOM project]

NUTS	Name	RES_ZONE	Forest [kt d.m./year]	Agriculture [kt d.m./year]	Biowaste [kt d.m./year]
DK050	Nordjylland	DK1	253	274	201
DK041	Vestjylland	DK1	241	249	148
DK042	Ostjylland	DK1	332	203	291
DK032	Sydjylland	DK1	305	299	248
DK031	Fyn	DK1	174	121	168
DK013	Nordsjaelland	DK2	93	49	155
DK012	Kobenhavns omegn	DK2	9	12	180
DK011	Byen Kobenhavn	DK2	0	6	244
DK021	Ostsjaelland	DK2	42	28	82
DK022	Vest- og Sydsjaelland	DK2	350	222	201
DK014	Bornholm	Bornholm	50	20	14
DK0	**Denmark**	**Total**	**1850**	**1484**	**1931**

To assess the energy content of the feedstocks available we have used the energy content (LHV) used by the European Commission for the calculation of the default values of the Renewable Energy Directive (Giuntoli et al., 2017), as reported in Tab.2. To be noted, the energy content refers to the dry part of the biomass.

This approach reflects the limited impact of the water content of gasification processes, on the contrary of combustion, where the moisture content of the fuel is determinant.

Table 2 - Energy content of the feedstocks

ENERGY CONTENT	**LHV** MJ/kg
Forest residues and stumps	19
Straw	17.2
Prunings	18
Lanscape care biomass	18
Saw mill & wood industries residues	19
Pulp and paper industries secondary residues	18
Food processing residues	18
Waste	20.7
Post consumer wood	18

In order to be able to assess whether the residual biomass and waste are sufficient to cover the full balancing needs of the RES-dominated zones, the efficiency of the W2G plant is needed. Six potential designs of the W2G plant were identified as the likely best options for the W2G concept deployment in WP2, WT 2.2 and reported in Tab.3.

Table 3 Process efficiencies for 6 potential W2G designs provided by D2.1 with the six designs evenly distributed in the Pareto front obtained.

Design option	Solution index	Biomass LHV input [kW]	Biomass HHV input [kW]	PowGen mode[a] [kW]	PowSto mode[b] [kW]	PowGen eff [%]	PowSto eff [%]
1	7708	19092	20306	9323	21613	48.8	65.9
2	7943	19092	20306	7494	16005	39.3	52.4
3	7420	19092	20306	5811	13840	30.4	44.6
4	2085	19092	20306	7169	29005	37.6	74.6
5	6260	19092	20306	8348	21370	43.7	60.7
6	1217	19092	20306	7001	13544	36.7	46.7

a Net power produced by the PowGen mode or the electricity exported to the electrical grid
b Net power consumption by the PowSto mode or the electricity input from the electrical grid

By combining the waste availability and process designs, we have identified the constraints to the deployment of the W2G plant in terms of maximum power consumption in power storage mode (SOEC) and power production in power generation mode (SOFC) with the following approach:

(1) The energy content of the biomass was calculated by multiplying the amount of each type of biomass in each area by the specific energy content (LHV).

(2) The biomass need (in MWh) for each operation mode (PowGen or PowSto mode) was calculated by multiplying the total amount of DOWN or UP balancing energy need (in MWh) of the RES-dominated areas the factors *f*:

$$f = \begin{cases} \dfrac{\text{Biomass LHV input}}{\text{PowGen power generation}} & \text{for PowGen mode (UP mode)} \\ \dfrac{\text{Biomass LHV input}}{\text{PowSto power consumption}} & \text{for PowSto mode (DOWN mode)} \end{cases}$$

(3) If there was enough biomass, the maximum W2G capacity corresponded to the maximum DOWN or UP power balancing need. Therefore, we have identified the zones in which the biomass was not a constraint for deploying the W2G plants.

(4) If the biomass was not enough to completely satisfy the power balancing needs with a specific design, we have calculated the **maximum energy capacity (not power capacity)** of the W2G plants by multiplying the total available biomass by the inverse of the factor *f* of the considered plant design to estimate the maximum energy that can be either stored or produced from that specific amount of biomass energy content.

(5) The total amount of energy potentially stored or produced was then compared with the cumulative amount of energy UP or DOWN to determine **the maximum power capacity** of the W2G plants. The cumulative energy demand or production is calculated by multiplying the power demand for each class of capacity by the number of hours per year that the power grid is in need of that specific balancing capacity.

We have therefore identified the maximum potential installed power capacity for each RES dominated zone, both in UP (power generation PowGen mode, when the rSOC is operated as SOFC) and DOWN (power storage PowSto mode, when the rSOC is operated as SOEC).

These limits represent the technical sustainable potential, they do not account for competition with other ways of utilizing the biomass and waste, as these will depend on the economic performances of the technology and markets and policies, which are not accounted for in this deliverable.

3. Results

In this section, we present the results obtained by applying the methodology described in section 3 to the 4 RES-dominated zones identified in D1.1. The balancing needs (Residual load) based on the historical data of aggregated wind and solar power generation (only considering vRES in the W2G project) and the gross consumption for the RES-dominated zones both in Denmark and Italy were previously investigated in WT1.1. Those results are here compared with the power maximum capacity obtainable from the future availability (2030 time horizon) of biomass wastes and residues by applying the W2G plant, taking into account six different reliable designs (D1, D2, D3, D4, D5 and D6) and the corresponding efficiencies.

Table 4, 5, 6 and 7 report the results regarding availability of biomass with respect to the energy needs for the two examined modes of operation, i.e. power generation mode (corresponding to UP) and power storage mode (corresponding to DOWN), for the identified RES-dominated zones in Denmark and Italy: DK1, DK2, Bornholm and SUD.

The 'Total waste availability' is the total energy content of waste and residues for the area expressed as MWh or GWh.

'Biomass needs UP' is the amount of biomass required as gasification feedstock to fuel the rSOC operated as SOFC to produce the electricity required to balance the power grid.

'Biomass need DOWN' shows the total amount of biomass needed to produce the amount of syngas required to match the amount of excess electricity in the power grid to stoichiometrically produce methane to be injected into the gas grid.

The 'Total biomass needs' is the sum of 'Biomass needs DOWN' and 'Biomass need UP'.

If the 'Total biomass needs' is larger than the 'Total biomass availability', there is a surplus of biomass and the only constraint to the W2G plant deployment are balancing needs of the power grid.

The cells in red highlight the cases in which the residues and waste are not sufficient to cover fully the balancing demand of the power grid.

3.1.Denmark DK1

For DK1, in UP mode, the amount of available biomass satisfies the energy demand for all the given plant designs. The biomass availability is not a constraint to operate the rSOC as SOFC, and the local biomass is able to balance the excess electricity in the power grid. The same is in DOWN mode for D1, D4 AND D5, whereas, as shown in Fig. 3 (DK1), the amount of biomass available is sufficient to run a maximum capacity of 5700, 5900 and 6300 MW for rSOC power storage mode (SOEC), with D6, D3 and D2, respectively.

Table 4 DK1 - Comparison between the power grid needs and the local biomass wastes and residues availability by adopting the W2G plants in the 6 proposed designs.

Denmark - DK1	Unit	DESIGN 1	DESIGN 2	DESIGN 3	DESIGN 4	DESIGN 5	DESIGN 6
Total waste availability	GWh	16,805	16,805	16,805	16,805	16,805	16,805
Biomass needs DOWN	GWh	15,016	20,278	23,451	15,016	15,187	23,964
Biomass needs UP	GWh	9,917	12,337	15,910	12,897	11,075	13,205
Total biomass needs	GWh	24,934	32,615	39,361	27,913	26,262	37,169
Total biomass needs/ biomass availability	%	148.4%	194.1%	234.2%	166.1%	156.3%	221.2%
Biomass needs DOWN/ biomass availability	%	89.4%	120.7%	139.5%	89.4%	90.4%	142.6%
Biomass needs UP/ biomass availability	%	59.0%	73.4%	94.7%	76.7%	65.9%	78.6%

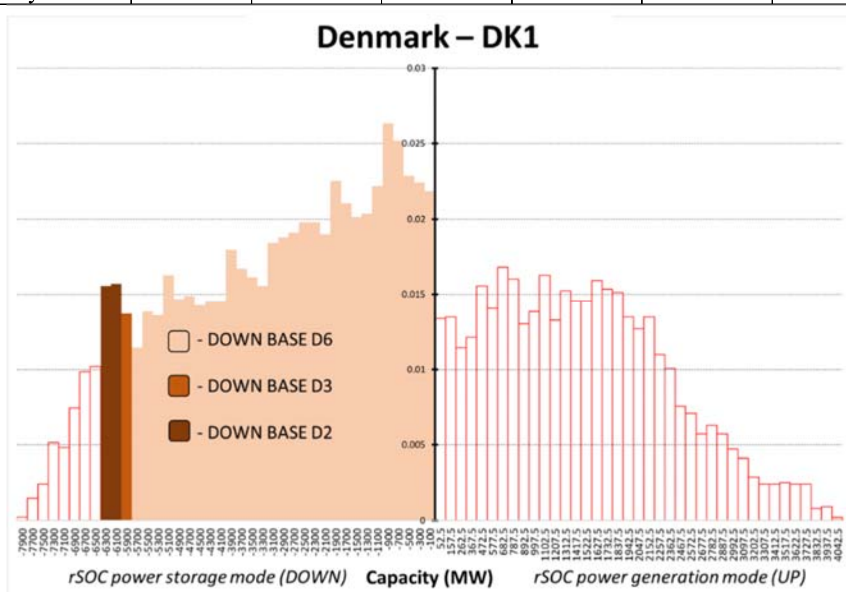

Figure 3 Frequency histogram of the hourly UP/DOWM power capacity in Denmark zone 1 (DK1) in 2030. Full colored bars indicate the maximum capacity of a specific W2G plant design (D), taking into account the local biomass availability to balance the power grid, BASE scenario 2030. Not indicated designs imply local biomass availability fulfilling the energy demand in that configuration.

3.2 Denmark DK2

For the DK2 (Fig. 4), in DOWN mode, the biomass required to fulfill the power balancing needs is lower with respect than the local availability of biomass. Differently, in UP mode, the biomass required to balance the power grid is considerably higher and the amount of biomass potentially available in 2030, resulting not enough for all six energy setting scenarios. Specifically, the amount of biomass available is sufficient to run a maximum capacity of 412 MW (D3 and D6) and 487 MW (D1, D2, D4 and D5) for the PowGen mode.

Table 5 DK2 - Comparison between the power grid needs and the local biomass wastes and residues availability by adopting the W2G plants in the 6 proposed designs

Denmark - DK2	**Unit**	**DESIGN 1**	**DESIGN 2**	**DESIGN 3**	**DESIGN 4**	**DESIGN 5**	**DESIGN 6**
Total waste availability	GWh	8,333	8,333	8,333	8,333	8,333	8,333
Biomass needs DOWN	GWh	925	1,250	1,445	925	936	1,477
Biomass needs UP	GWh	14,635	18,206	23,479	19,032	16,343	19,487
Total biomass needs	GWh	15,561	19,456	24,924	19,957	17,279	20,964
Total biomass needs/ biomass availability	%	186.7%	233.5%	299.1%	239.5%	207.4%	251.6%
Biomass needs DOWN/ biomass availability	%	11.1%	15.0%	17.3%	11.1%	11.2%	17.7%
Biomass needs UP/ biomass availability	%	175.6%	218.5%	281.8%	228.4%	196.1%	233.9%

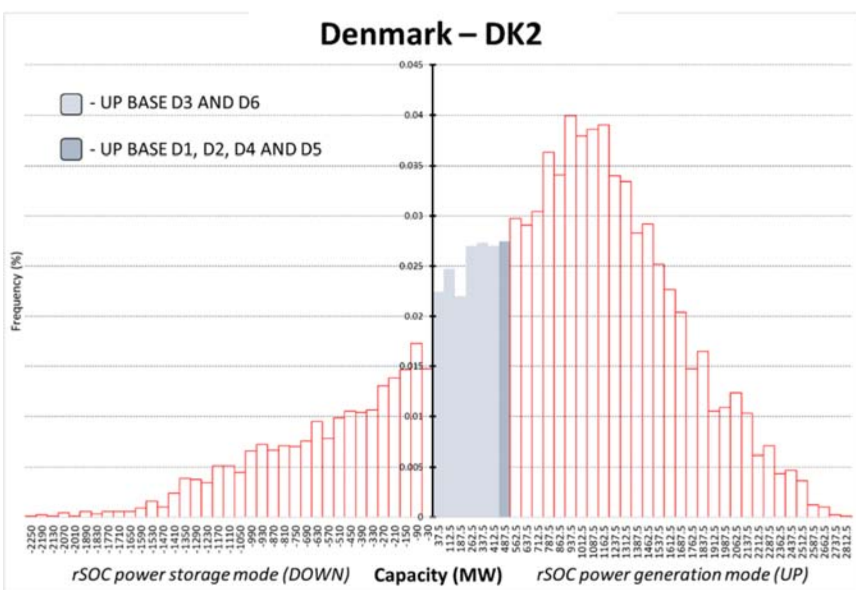

Figure 4 Frequency histogram of the hourly UP/DOWM power capacity in Denmark zone2 (DK2) in 2030. Full colored bars indicate the maximum capacity of a specific W2G plant design (D), taking into account the local biomass availability to balance the power grid, 2030 BASE scenario. Not indicated designs imply local biomass availability fulfilling the energy demand in that configuration.

3.3 Denmark Bornholm

In the Bornholm RES-dominated zone, the amount of biomass wastes and residues availability is not a constraint (Fig. 5) as it is enough to balance the power grid by adopting the W2G plant, in both rSOC UP and DOWN modes. However, the total biomass availability is not enough to satisfy both the UP and DOWN balancing needs.

Table 6 Borholm - Comparison between the power grid needs and the local biomass wastes and residues availability by adopting the W2G plant in the 6 proposed designs.

Denmark – Bornholm	**Unit**	**DESIGN 1**	**DESIGN 2**	**DESIGN 3**	**DESIGN 4**	**DESIGN 5**	**DESIGN 6**
Total waste availability	MWh	290,215	290,215	290,215	290,215	290,215	290,215
Biomass needs DOWN	MWh	95,725	129,269	149,492	95,725	96,813	152,763
Biomass needs UP	MWh	178,912	222,562	287,017	232,657	199,788	238,226
Total biomass needs	MWh	274,637	351,831	436,510	328,382	296,602	390,988
Total biomass needs/ biomass availability	%	94.6%	121.2%	150.4%	113.2%	102.2%	134.7%
Biomass needs DOWN/ biomass availability	%	33.0%	44.5%	51.5%	33.0%	33.4%	52.6%
Biomass need UP/ biomass availability	%	61.6%	76.7%	98.9%	80.2%	68.8%	82.1%

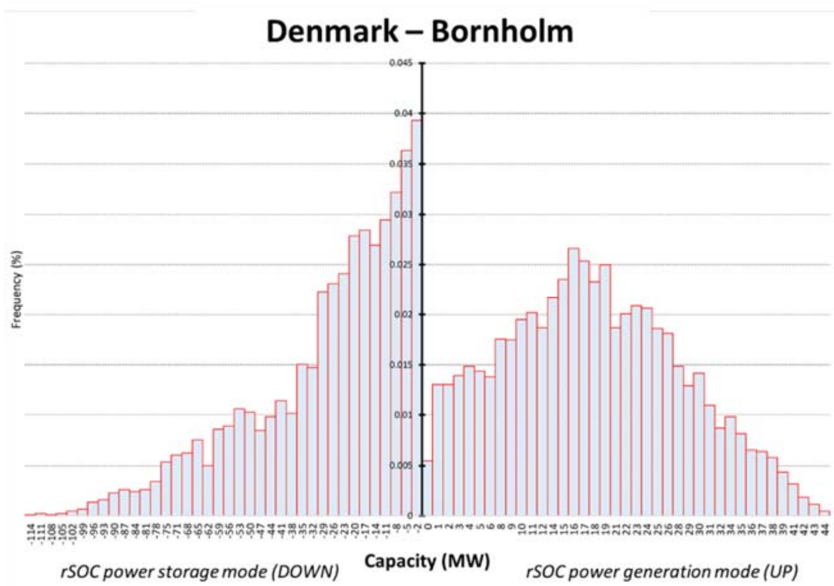

Figure 5 Frequency histogram of the hourly UP/DOWM power capacity in Bornholm (DK) in 2030. Full colored bars indicate the maximum capacity of a specific W2G plant design (D), taking into account the local biomass availability to balance the power grid, 2030 BASE scenario. Not indicated designs imply local biomass availability fulfilling the energy demand in that configuration.

3.4 Italy SUD

In the Southern Italy zone (Fig. 6), in DOWN mode the biomass required to fulfill the balancing power needs are low, thus the local availability of biomass is enough. Differently, in UP mode, in Italy SUD, the biomass required to balance the power grid is considerably higher and the amount of biomass potentially available in 2030, resulting not enough in all six plant designs. Specifically, the amount of biomass available is sufficient to run a maximum capacity of 2188 MW (D3), 2438 MW (D2, D4 and D6), 2688 MW (D5) and 2813 MW (D1).

Table 7 Southern Italy - Comparison between the balancing grid needs and the local biomass wastes and residues availability by adopting W2G plant in the 6 proposed designs

Southern Italy	Unit	DESIGN 1	DESIGN 2	DESIGN 3	DESIGN 4	DESIGN 5	DESIGN 6
Total waste availability	GWh	19,110	19,110	19,110	19,110	19,110	19,109,711
Biomass needs DOWN	GWh	655	885	1,023	655	663	1,045,614
Biomass needs UP	GWh	27,803	34,586	44,602	36,154	31,047	37,019,690
Total biomass needs	GWh	28,458	35,470	45,625	36,809	31,709	38,065,305
Total biomass needs/ biomass availability	%	148.9%	185.6%	238.8%	192.6%	165.9%	199.2%
Biomass needs DOWN/ biomass availability	%	3.4%	4.6%	5.4%	3.4%	3.5%	5.5%
Biomass needs UP/ biomass availability	%	145.5%	181.0%	233.4%	189.2%	162.5%	193.7%

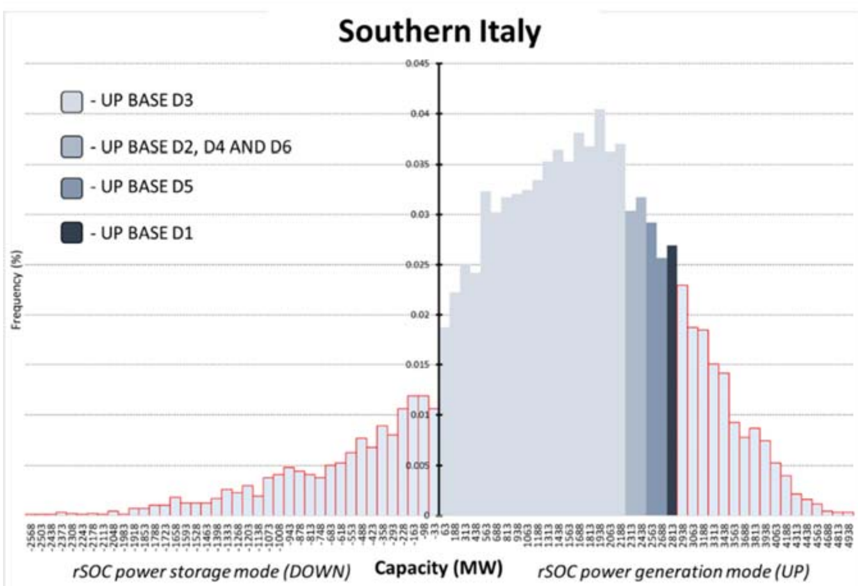

Figure 6 Frequency histogram of the hourly UP/DOWM power capacity in Southern Italy in 2030. Full colored bars indicate the maximum capacity of a specific W2G plant design (D), considering the local biomass availability to balance the power grid, 2030 BASE scenario. Not indicated designs imply local biomass availability fulfilling the energy demand in that configuration.

4. Discussion and conclusions

Climate change is happening. The UN International Panel on Climate Change (IPCC), has stated, with high confidence, that human activities have caused approximately 1.0 °C of global warming above pre-industrial levels, and global warming is likely to reach 1.5 °C between 2030 and 2052 if it continues to increase at the current rate (Myles et al., 2018).

Greenhouse gas (GHG) emissions resulting from the provision of energy services have contributed significantly to the historic increase in atmospheric GHG concentrations. Since approximately 1850, global use of fossil fuels (coal, oil and gas) has increased to dominate energy supply, leading to a rapid growth in carbon dioxide (CO2) emissions (Edenhofer et al., 2011). Demand for energy and associated services, to meet social and economic development and improve human welfare and health, is increasing. All societies require energy services to meet basic human needs and to serve productive processes.

Historically, economic development has been strongly correlated with increasing energy use and growth of GHG emissions, and renewable energy (RE) can help decouple that correlation (Edenhofer et al., 2011).

In its EU2020 climate and energy package, the European Union passed a directive on renewable energy in 2009: The Renewable Energy Directive (RED) (European Parliament, 2009). The RED set targets for renewable energy at 20% by 2020. In November 2016, the European Commission published the so-called 'winter package' a set of measures part of the 'Clean Energy for all Europeans' initiative. A recast of the RED was included in the package. In 2018 the European Union has agreed on a set of ambitious targets in its 2030 energy union strategy, with renewables expected to cover 32 % of the total energy consumption. (European Union, 2018).

To reach such an overall renewable energy target, in 2030 the EU needs to meet more than 50 % of its gross electricity generation needs using renewable technologies, as the power sector is easier (and cheaper) to decouple from fossil fuels than other systems (e.g. transport) (Banja et al., n.d.).

However, the large penetration of intermittent, non-dispatchable renewable energy (i.e. wind and solar), pose serious threats to the stability and balancing of the power grid and generate an increasing need for energy storage with elevated capacity combined with high charge/discharge periods (Venkataraman et al., 2019).

While there are trade-offs among the performances of storage technologies (Venkataraman et al., 2019), the European natural gas grid has already a significant capacity, higher than one fifth of the total natural gas consumption (GIE, n.d.), which is an excellent opportunity for inter-seasonal energy storage (i.e. storing the summer solar excess electricity for the winter).

The W2G project has investigated what is the potential of using organic waste and residues to both store the excess power produced by vRES into the natural gas grid and the fulfilling of the balancing needs when the vRES are not enough.

We have matched the power grid balancing needs and the waste availability in the selected RES dominated areas to explore the maximum potential capacities of the W2G plant both in power storage mode and power generation mode. In power storage mode the W2G system uses excess power from non-dispatchable renewables combined with syngas from waste gasification to produce methane to be injected in the natural gas grid for storage. In power generation mode the syngas produced from waste is used in the SOFC to produce power.

We found that in most cases the amount of waste and residues is enough to match the DOWN balancing need of the power grid (PowSto mode). Only in DK1 the amount of waste and residues was not sufficient to deal with the large excess electricity from renewables with all the W2G process designs (only for 3 out of 6).

As regards the UP mode, the generation of electricity to be fed into the power grid, we found that the residues were enough for two of the 4 zones selected (DK1 and Bornholm), while for SUD and DK1 the residues and waste are not enough to generate all the electricity need by the power grid. Only in one case out of the 24 combinations (4 RES-dominated areas and 6 designs), the biomass was sufficient for both the UP and DOWN balancing needs, namely the design 1 in the Bornholm island.

The potential capacity for the deployment of the W2G plant is impressive, with and order of magnitude of the few GWh of electricity produced or stored per year for DK1, DK2 and SUD (tens of MWh for Bornholm).

These results are however technical potential, they are not meant to represent the optimal solution, but rather to set a constraint to the maximum deployment of the technology and support the identification of the optimal design and sizing of the technology which will depend on the economic competition with other energy storage technologies and competition for the feedstocks for the DOWN mode, while it will compete with other power sources for the generation mode.

5. List of references

Banja, M., Jégard, M., Europäische Kommission Gemeinsame Forschungsstelle, n.d. Renewable technologies in the EU electricity sector trends and projections : analysis in the framework of the EU 2030 climate and energy strategy.

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Eickemeier, P., Matschoss, P., Hansen, G., Kadner, S., Schlömer, S., Zwickel, T., Stechow, C. Von, 2011. IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation Summary for Policymakers and Technical Summary, Intergovernmental Panel on Climate Change IPCC. https://doi.org/10.5860/CHOICE.49-6309

European Parliament, 2009. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009. Off. J. Eur. Union 140, 16–62. https://doi.org/10.3000/17252555.L_2009.140.eng

European Union, 2018. DIRECTIVE (EU) 2018/2001 on the promotion of the use of energy from renewable sources (recast) [WWW Document]. 11 December . URL https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32018L2001&from=EN (accessed 2.15.19).

EUROSTAT, n.d. Transboundary waste shipments - Eurostat [WWW Document]. URL https://ec.europa.eu/eurostat/web/waste/transboundary-waste-shipments (accessed 11.2.19).

GIE, n.d. Existing gas storage capacity in Europe exceeded one petawatthour in 2018, shrinked against 2016 | GIE [WWW Document]. URL https://www.gie.eu/index.php/gie-media/press-releases/13-news/gie/379-press-release-existing-gas-storage-capacity-in-europe-exceeded-one-petawatthour-in-2018-shrinked-against-2016 (accessed 11.2.19).

Giuntoli, J., Agostini, A., Edwards, R., Marelli, L., 2017. Solid and gaseous bioenergy pathways: input values and GHG emissions: Calculated according to methodology set in COM(2016) 767: Version 2 - European Commission. https://doi.org/10.2790/27486

Malinauskaite, J., Jouhara, H., Czajczyńska, D., Stanchev, P., Katsou, E., Rostkowski, P., Thorne, R.J., Colón, J., Ponsá, S., Al-Mansour, F., Anguilano, L., Krzyżyńska, R., López, I.C., A.Vlasopoulos, Spencer, N., 2017. Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe. Energy 141, 2013–2044. https://doi.org/10.1016/J.ENERGY.2017.11.128

Myles, A., Mustafa, B., Yang, C., de Coninck, H., 2018. Global Warming of 1.5°C. Summary for Policymakers. IPPC. https://doi.org/10.1016/j.foreco.2011.10.013

NYT, n.d. A Whiff of Naples Arrives in Hamburg - The New York Times [WWW Document]. URL https://www.nytimes.com/2008/06/09/world/europe/09trash.html (accessed 11.2.19).

Venkataraman, V., Pérez-Fortes, M., Wang, L., Hajimolana, Y.S., Boigues-Muñoz, C., Agostini, A., McPhail, S.J., Maréchal, F., Van Herle, J., Aravind, P.V., 2019. Reversible solid oxide systems for energy and chemical applications – Review & perspectives. J. Energy Storage 24, 100782. https://doi.org/10.1016/J.EST.2019.100782