Energy savings from deep renovation of buildings

The new streamSAVE Plus methodology to calculate energy savings from deep renovation of buildings (residential and non-residential)

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Deep renovation

Key aspects	Actions	Benefits	Challenges (methodology aspect)
• Extensive energy performance improvement • Whole building approach • Long-term impact • Reduction of carbon footprint	• Building envelope • HVAC systems • Electrical systems • RES integration	• > 60% reduction in primary energy use • Cost reduction • GHG emission reduction • Indoor comfort and health • Property value • Job creation (local)	• Definition (nZEB, ZEB) varies among MS based on cost-optimal calculations • Actions leading to nZEB or ZEB depend on the starting point of a building

‘deep renovation’ means a renovation which is in line with the ‘energy efficiency first’ principle, which focuses on essential building elements and which transforms a building or building unit:

- **before 1 January 2030, into a nearly zero-energy (nZEB) building**
- **from 1 January 2030, into a zero-emission (ZEB) building**

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Calculation of final energy savings (Article 8)

- The total final energy savings are calculated reflecting the effect of a bundle of deep renovation measures and are determined based on the difference in annual energy consumption for heating needs of the building before and after the renovation (space heating and domestic hot water), but with included energy consumption for other building services as well, such as lighting, ventilation and cooling

$$TFES = (FEC_{before,Art8} - FEC_{after,Art8}) * f_{BEH}$$

TFES	Total final energy savings [kWh/year] due to deep renovation of the building
$FEC_{before,Art8}$	Final energy consumption before deep energy renovation [kWh/ year]
$FEC_{after,Art8}$	Final energy consumption after deep energy renovation, i.e. after both thermal renovation and technology renovation [kWh/ year]
f_{BEH}	Factor to calculate behavioural aspects taking into account rebound effect, spill-over effect and free-rider effect [dmnl]

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Calculation of final energy savings (Article 8)

$$FEC_{before,Art8} = \left(\sum_{i}^{n} \frac{SHD_{before} * w_{SHD,i,before}}{\eta_{SHD,i,before}} + \sum_{i}^{n} \frac{HWD_{before} * w_{HWD,i,before}}{\eta_{HWD,i,before}} + E_{L,before} + E_{V,before} + E_{C,before}\right) \cdot A_{before} \cdot cf_x$$

$$FEC_{after,Art8} = \left(\sum_{i}^{n} \frac{SHD_{after} * w_{SHD,i,after}}{\eta_{SHD,i,after}} + \sum_{i}^{n} \frac{HWD_{after} * w_{HWD,i,after}}{\eta_{HWD,i,after}} + E_{L,after} + E_{V,after} + E_{C,after}\right) \cdot A_{after} \cdot cf_x$$

A_{before}	Conditioned floor area of the building before deep renovation[m²]
cf_x	Climate correction factor [dmnl]
SHD_{before}	Specific area space heating demand of the building before deep energy renovation [kWh/m²year]
$w_{SHD,i,before}$	The share of the energy demand for area space heating of the building attributable to the respective energy source before deep energy renovation [dmnl] If only one source is used, the common coefficient $w_{SHD,before} = 1$. If a system of multiple energy sources with one average seasonal efficiency for whole system is used, the common coefficient $w_{SHD,before} = 1$. In other cases, the coefficient for each energy source shall be used, where $w_{SHD,i,old} < 1$ and $\sum_i^n w_{SHD,i,old} = 1$.
$\eta_{SHD,i,before}$	Annual operating efficiency of the old (replaced) building heating system by energy carrier before deep energy renovation [dmnl]
HWD_{before}	Domestic hot water demand before deep energy renovation [kWh/m²year]
$w_{HWD,i,before}$	The share of the energy demand for domestic hot water preparation attributable to the respective energy source before deep energy renovation [dmnl] If only one source is used, the common coefficient $w_{HWD,before} = 1$. If a system of multiple energy sources with one average seasonal efficiency for whole system is used (e.g. heat pump with bivalent energy source), the common coefficient $w_{HWD,before} = 1$. In other cases, the coefficient for each energy source shall be used, where $w_{HWD,i,old} < 1$ and $\sum_i^n w_{HWD,i,old} = 1$.
$\eta_{HWD,i,before}$	Annual operating efficiency of the old (replaced) domestic hot water system by energy carrier before deep energy renovation [dmnl]
$E_{L,before}$	Building energy consumption for lighting before deep energy renovation [kWh/m²year]
$E_{V,before}$	Building energy consumption for ventilation system before deep energy renovation [kWh/m²year]
$E_{C,before}$	Building energy consumption for cooling before deep energy renovation [kWh/m²year]

* Same meaning for '*after*'

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Calculation of final energy savings (Article 8)

Indicative values for the final energy consumption and specific energy demand per building type

Parametar [kWh/m²*year]	Residential sector	Non-residential sector
$FEC_{before,Art8}$ per useful area of a building	149.29	216.45
$FEC_{after,Art8}$ per useful area of a building	59.716	86,58
SHD_{before}	88.29	119.87
SHD_{after}	35.32	47.95
HWD_{before}	14.65	18.82
HWD_{after}	5.86	7.528
$E_{L,before}$	3.40	16.06
$E_{L,after}$	Depending on type of individual actions	Depending on type of individual actions
$E_{V,before}$	0 (no ventilation considered) *	4.83
$E_{V,after}$	Depending on type of individual actions	Depending on type of individual actions
$E_{C,before}$	2.86 or 0 (if the cooling system is not present)	9.09
$E_{C,after}$	Depending on type of individual actions	Depending on type of individual actions

Indicative values for efficiency of heating system

η_{before} – weighted value	Residential sector	Non-residential sector
Heating - $\eta_{SHD,before}$	0.730	0.807
Domestic hot water - $\eta_{HWD,before}$	0.723	0.708
η_{after} – weighted value	**Residential sector**	**Non-residential sector**
Heating - $\eta_{SHD,after}$	0.902	1.015
Domestic hot water - $\eta_{HWD,after}$	0.835	0.870

Indicative values for climate correction factor

c_{fx} [dmnl]	Residential sector			Non-residential sector		
	North	West	South	North	West	South
Total **final energy consumption**, consisting of	1,30	1,00	0,82	0,96	1,00	0,79
Space heating	1,35	1,00	0,73	1,00	1,00	0,66
Space cooling	0,82	1,00	2,58	0,85	1,00	1,50
Water heating	0,94	1,00	0,95	0,93	1,00	1,07
Lighting	1,12	1,00	1,03	1,03	1,00	1,05
Venilation	-	-	-	1,08	1,00	1,13
Specific energy demand for						
Space heating	1,42	1,00	0,66	0,97	1,00	0,70
Water heating	0,96	1,00	0,93	0,91	1,00	0,96

Indicative values for behavioural impact factor

f_{BEH}	[dmnl]
Residential sector	0.70
Non/residential sector	0.90

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Important issue: efficiency of the system

Case 1: no detailed system information ($\eta_{SHD,before}$ and $\eta_{HWD,before}$) is known

- Use weighted average values (see previous slide)
- Also available: Indicative values for efficiency of a reference heating system before and after retrofit per energy carrier

η_{before} – reference heating system per energy carrier	Residential sector		Non-residential sector	
	Heating - $\eta_{SHD,before}$	Domestic hot water - $\eta_{HWD,before}$	Heating - $\eta_{SHD,before}$	Domestic hot water - $\eta_{HWD,before}$
Solids	0.669	0.685	0.645	0.674
Liquified petroleum gas (LPG)	0.602	0.675	0.651	0.607
Diesel oil	0.573	0.600	0.589	0.578
Natural gas	0.668	0.668	0.681	0.654
Gas heat pumps	-	-	2.266	-
Conventional gas heaters	-	-	0.675	-
Biomass	0.649	0.719	0.549	0.682
Geothermal	0.800	0.838	0.835	-
Distributed heat	0.796	0.838	0.826	0.828
Advanced electric heating	2.669	0.689	2.694	0.704
Conventional electric heating	0.751		0.753	
Electricity in circulation	1.000	-	1.000	-
Solar	-	1.000	-	1.000

η_{after} – reference heating system in 2021	Heating - $\eta_{SHD,after}$	Domestic hot water - $\eta_{HWD,after}$	Heating - $\eta_{SHD,after}$	Domestic hot water - $\eta_{HWD,after}$
Gas heat pumps	-	-	2.900	-
Biomass	0.774	0.849	0.584	0.818
Geothermal	0.856	0.878	0.872	-
Distributed heat	0.853	0.901	0.885	0.899
Advanced electric heating	3.581	-	3.561	-
Conventional electric heating	0.892	0.770	0.872	0.884
Electricity in circulation	1.000	-	1.000	-
Solar	1.000	1.000	-	1.000

Important issue: efficiency of the system

Case 2: The efficiency of the source ($\eta_{s,SHD}$ or $\eta_{s,HWD}$) is known, but the efficiencies about distribution system are not known

- $\eta_{s,SHD,i}$ is the standardized seasonal efficiency of the heat source for heating
- $\eta_{sys,SHD,i}$ is efficiency of heating system without efficiency of heat source
- Same approach for hot water preparation

$$\eta_{SHD,i} = \eta_{s,SHD,i} \cdot \eta_{sys,SHD,i}$$

$$\eta_{sys,SHD,i} = \eta_{dis,SHD,i} \cdot \eta_{em,SHD,i} \cdot \eta_{c,SHD,i}$$

$$\eta_{HWD,i} = \eta_{s,HWD,i} \cdot \eta_{sys,HWD,i}$$

η_s	Residential sector		Non-residential sector	
	Heating - $\eta_{s,SHD,min}$	Domestic hot water - $\eta_{s,HWD,min}$	Heating - $\eta_{s,SHD,min}$	Domestic hot water - $\eta_{s,HWD,min}$
Biomass	0.750	0.750	0.770	0.770
Geothermal	0.869	0.890	0.872	0.890
Distributed heat	0.838	0.876	0.885	0.876
Advanced electric heating	3.100	1.100	3.100	1.100
Conventional electric heating	0.360	0.370	0.360	0.370
Electricity in circulation	1.000	1.000	1.000	1.000
Solar	1.000	1.000	1.000	1.000

SPF_{SHD}	Value
Electrically driven	
Air sourced heat pump	2.6
Ground-air heat pump	3.2
Ground-water heat pump	3.5
Driven by thermal energy	
Air sourced heat pump	1.2
Ground-air heat pump	1.4
Ground-water heat pump	1.6
SPF_{HWD}	
All types of electrically driven heat pumps	2.4
All types of thermal heat pumps	1.1

Part of heating system	System before	System after
Heating system efficiency – $\eta_{sys,SHD}$	0.68	0.86
Heat distribution efficiency – $\eta_{dis,SHD}$	0.93	0.97
Heat emission efficiency – $\eta_{em,SHD}$	0.78	0.93
Heat control system efficiency – $\eta_{c,SHD}$	0.94	0.95
Hot water system – $\eta_{sys,HWD}$	0.3-0.75	0.6-0.75

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Important issue: efficiency of the system

Case 3: The source and system efficiency values are known

- Can be taken from national values, energy performance certificates, assessments for specific building (audit)
- Same approach as in Case 2
- If some values are unknown - combine

$$\eta_{SHD,i} = \eta_{s,SHD,i} \cdot \eta_{sys,SHD,i}$$

$$\eta_{sys,SHD,i} = \eta_{dis,SHD,i} \cdot \eta_{em,SHD,i} \cdot \eta_{c,SHD,i}$$

$$\eta_{HWD,i} = \eta_{s,HWD,i} \cdot \eta_{sys,HWD,i}$$

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Calculation of cumulative savings (Article 8)

- The formula takes into account the different lifetimes of construction and technological measures
- The first step calculates the energy savings from building measures (only thermal renovation of building envelope) that have a longer lifetime, then
- Only the savings from technological measures with a shorter lifetime are calculated

$$\boldsymbol{TFES_{cumulative} = TFES_{con} + TFES_{tech}}$$

Cumulative energy savings in given year n after deep renovation

$$\boldsymbol{TFES_{cumulative,n}} = \left(\frac{\boldsymbol{TFES_{con}}}{lt_{con}} + \frac{\boldsymbol{TFES_{tech}}}{lt_{tech}}\right) * \boldsymbol{n}$$

1st step – thermal renovation

$$\boldsymbol{TFES_{con}} = (\boldsymbol{FEC_{before,Art8}} - \boldsymbol{FEC_{after,con,Art8}}) * f_{BEH} * lt_{con}$$

Whereas*:

$$\boldsymbol{FEC_{before,Art8}} = \left(\sum_i^n \frac{\boldsymbol{SHD_{before}} * w_{SHD,i,before}}{\eta_{SHD,i,before}} + \sum_i^n \frac{HWD_{before} * w_{HWD,i,before}}{\eta_{HWD,i,before}} + E_{L,before} + E_{V,before} + E_{C,before}\right) \cdot A_{before} \cdot cf_x$$

$$\boldsymbol{FEC_{after,con,Art8}} = \left(\sum_i^n \frac{\boldsymbol{SHD_{after,con}} * w_{SHD,i,before}}{\eta_{SHD,i,before}} + \sum_i^n \frac{HWD_{before} * w_{HWD,i,before}}{\eta_{HWD,i,before}} + E_{L,before} + E_{V,before} + E_{C,before}\right) \cdot A_{after,con} \cdot cf_x$$

*The gray part of the calculation can be ignored in the 1st step, because it does not affect the result. Changes in technology are only addressed in the 2nd step.

2nd step – technology improvements

$$\boldsymbol{TFES_{tech}} = (\boldsymbol{FEC_{after,con,Art8}} - \boldsymbol{FEC_{after,Art8}}) * f_{BEH} * lt_{tech}$$

Whereas:

$$\boldsymbol{FEC_{after,con,Art8}} = \left(\sum_i^n \frac{SHD_{after,con} * w_{SHD,i,before}}{\eta_{SHD,i,before}} + \sum_i^n \frac{HWD_{before} * w_{HWD,i,before}}{\eta_{HWD,i,before}} + E_{L,before} + E_{V,before} + E_{C,before}\right) \cdot A_{after,con} \cdot cf_x$$

$$\boldsymbol{FEC_{after,Art8}} = \left(\sum_i^n \frac{SHD_{after} * w_{SHD,i,after}}{\eta_{SHD,i,after}} + \sum_i^n \frac{HWD_{after} * w_{HWD,i,after}}{\eta_{HWD,i,after}} + E_{L,after} + E_{V,after} + E_{C,after}\right) \cdot A_{after} \cdot cf_x$$

Lifetime of savings	[a]
Construction	>25
Technology	10
Air to air heat pump	10
Air to water heat pump	15
Geothermal heat pump	25
High-efficiency boilers (< 30 kW)	20
High-efficiency boilers (> 30 kW)	25
Efficient lighting systems	15
Efficient central air-conditioning and chillers	17
Efficient ventilation systems	15

Data sources for indicative calculation values

- Integrated Database of the European Energy System (IDEES) database
  - datasets “RES_hh_fecs” and “SER_hh_fecs for FEC_{before}
    - FEC_{after} at least 60% of FEC_{before}
  - datasets “RES_hh_tess” and “SER_hh_tess” for SHD and HWD
  - datasets “RES_hh_eff” and “SER_hh_eff” for system efficiencies
  - ventilation, lighting and cooling
  - climate factor
- Eco-design requirements - > EPREL database
- PRIMES model
- Literature review on energy performance gap related to occupant behaviour in post-retrofitted buildings

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Calculation of impact on energy consumption (Article 4)

$$EPEC = FEC_{Baseline} \cdot \sum_{ec} (share_{ec,Baseline} \cdot f_{PE,ec}) - FEC_{Action} \cdot \sum_{ec} (share_{ec,Action} \cdot f_{PE,ec})$$

EPEC	Effect on primary energy consumption [kWh/a]
FEC	Annual final energy consumption [kWh/a]
$share_{ec}$	Share of final energy carrier on final energy consumption [dmnl]
$f_{PE,ec}$	Final to primary energy conversion factor of the used energy carrier [dmnl]
Baseline	Index for the baseline situation of the action
Action	Index for the situation after the implementation of the action
ec	Index of energy carrier

Indicative values for residential buildings

$Share_{ec}$ – Baseline	Heating [%]	Domestic hot water [%]	Heating and DHW [%]
Solids	4.63	2.21	4.28
Liquefied petroleum gases	1.50	4.20	1.88
Gas/Diesel oil	13.42	10.23	12.96
Natural gas	38.88	37.71	38.71
Wood/wood waste	23.16	8.15	21.00
Geothermal energy	0.02	0.02	0.02
District heat	11.15	7.30	10.60
Electricity	7.23	24.08	9.65
Solar	0.00	6.09	0.88
$Share_{ec}$ – Action	**Heating [%]**	**Domestic hot water [%]**	**Heating and DHW [%]**
For heat pump			
Electricity	100.00	100.00	100.00
For biomass boiler			
Wood/wood waste	100.00	100.00	100.00
For district heating			
District heat	100.00	100.00	100.00

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Calculation of impact on energy consumption (Article 4)

$$EPEC = FEC_{Baseline} \cdot \sum_{ec} (share_{ec,Baseline} \cdot f_{PE,ec}) - FEC_{Action} \cdot \sum_{ec} (share_{ec,Action} \cdot f_{PE,ec})$$

EPEC	Effect on primary energy consumption [kWh/a]
FEC	Annual final energy consumption [kWh/a]
$share_{ec}$	Share of final energy carrier on final energy consumption [dmnl]
$f_{PE,ec}$	Final to primary energy conversion factor of the used energy carrier [dmnl]
Baseline	Index for the baseline situation of the action
Action	Index for the situation after the implementation of the action
ec	Index of energy carrier

Indicative values for non-residential buildings

$Share_{ec}$ – Baseline	Heating [%]	Domestic hot water [%]	Heating and DHW [%]
Solids	1.50	0.33	1.30
Liquified petroleum gas (LPG)	0.33	2.33	0.67
Diesel oil	17.17	15.40	16.87
Natural gas	43.05	30.86	41.01
Biomass	4.55	0.59	3.88
Distributed heat	0.43	9.33	12.39
Geothermal	13.01	0.00	0.36
Electricity	19.96	39.08	23.18
Solar	0.00	2.07	0.35
$Share_{ec}$ – Action	**Heating [%]**	**Domestic hot water [%]**	**Heating and DHW [%]**
For heat pump			
Electricity	100.00	100.00	100.00
For biomass boiler			
Wood/wood waste	100.00	100.00	100.00
For district heating			
District heat	100.00	100.00	100.00

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Calculation of impact on energy consumption (Article 4)

$$EPEC = FEC_{Baseline} \cdot \sum_{ec} (share_{ec,Baseline} \cdot f_{PE,ec}) - FEC_{Action} \cdot \sum_{ec} (share_{ec,Action} \cdot f_{PE,ec})$$

EPEC	Effect on primary energy consumption [kWh/a]
FEC	Annual final energy consumption [kWh/a]
$share_{ec}$	Share of final energy carrier on final energy consumption [dmnl]
$f_{PE,ec}$	Final to primary energy conversion factor of the used energy carrier [dmnl]
Baseline	Index for the baseline situation of the action
Action	Index for the situation after the implementation of the action
ec	Index of energy carrier

Energy carrier	factor final to primary [-]
Electricity	2.064
District heat	1.592
Natural gas	1.007
Gas/Diesel oil	1.117
Motor gasoline	1.117
Biodiesels	1.002
Biogasoline	1.002
Other liquid biofuels	1.002
Biogas	1.026
Wood/wood waste	1.002
Other primary solid biomass	1.002
Kerosene (other than jet kerosene)	1.117
Liquefied petroleum gases	1.117
Naphtha	1.117
Natural gas liquids	1.117
Petroleum coke	1.117
Refinery gas	1.117
Residual fuel oil	1.117
White spirit and SBP	1.117
Other petroleum products	1.117

Energy carrier	factor final to primary [-]
Anthracite	1.002
Lignite	1.002
Charcoal	1.002
Coal tar	1.002
Coke oven coke and lignite coke	1.002
Coking coal	1.002
Patent fuel	1.002
Sub-bituminous coal	1.002
Other bituminous coal	1.002
Industrial wastes	1.000
Blast furnace gas	1.089
Coke oven gas	1.089
Oxygen steel furnace gas	1.089

Calculation of greenhouse gas savings

$$GHGSAV = \left[FEC_{Baseline} \cdot \sum_{ec} \left(share_{ec,Baseline} \cdot f_{GHG,ec}\right) - FEC_{Action} \cdot \sum_{ec} \left(share_{ec,Action} \cdot f_{GHG,ec}\right)\right] * 10^{-6}$$

GHGSAV	Greenhouse gas savings [t CO_{2e} p.a.]
FEC	Annual final energy consumption [kWh/a]
share	Share of final energy carrier on final energy consumption [dmnl]
f_{GHG}	Emission factor of final energy carrier [g CO_2/kWh]
Baseline	Index for the baseline situation of the action
Action	Index for the situation after implementation of the action
ec	Index of energy carrier

Data sources for indicative calculation values

The **shares of energy carriers per end-use type and sector** are based on the IDEES database, dataset "RES_hh_fec" for final energy consumption

The **emission factor(s)** for energy carriers are taken from Annex VI of the Regulation on the monitoring and reporting of greenhouse gas emissions (2018/2066/EU)

Energy carrier	emission factor [g CO_2/kWh]
Electricity	104.39
District heat	194.70
Natural gas	201.96
Gas/Diesel oil	266.76
Motor gasoline	249.48
Biodiesels	0.00
Biogasoline	0.00
Other liquid biofuels	0.00
Biogas	0.00
Wood/wood waste	0.00
Other primary solid biomass	0.00
Kerosene (other than jet kerosene)	258.84
Liquefied petroleum gases	227.16
Naphtha	263.88
Natural gas liquids	231.12
Petroleum coke	351.00
Refinery gas	207.36
Residual fuel oil	278.64
White spirit and SBP	263.88
Other petroleum products	263.88

Energy carrier	emission factor [g CO_2/kWh]
Anthracite	353.88
Lignite	363.60
Charcoal	0.00
Coal tar	290.52
Coke oven coke and lignite coke	385.20
Coking coal	340.56
Patent fuel	351.00
Sub-bituminous coal	345.96
Other bituminous coal	340.56
Industrial wastes	514.80
Blast furnace gas	936.00
Coke oven gas	159.84

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Overview of costs

Deep renovation component	CAPEX excluding VAT [euro2024/kW]	OPEX excluding VAT [% of investment costs]
Complex insulation (average for combination of windows and walls/roofs/basement)	180 – 383 [euro2024/m^2]	/
Biomass boiler	150 – 472	2.0 – 4.0
Heat pump (air – water)	631 – 902	1.5 – 4.0
Heat pump (water – water)	834 – 1,191	
Heat pump (ground – water)	1,364 – 1,949	
Heat pump (gas)	1,352	
Electric resistance heating	69	0.5
District heating	84 - 105	0.5 – 1.5
Air conditioning (ventilation and cooling system)	158 - 665	2.0 – 4.0
Photovoltaic system	1,500 - 2,500	0.5 – 1.5
Solar thermal system (including water tank storage)	1,438	1.0 – 2.
Lighting (non-residential)	10	0.5 – 1.0

Sector	CAPEX excluding VAT [euro2024/m^2]
Residential	440 - 578
Non-residential	512 – 660

Data sources for indicative calculation values

Data from the EU Reference Scenario 2020, developed by the European Commission with the PRIMES energy system model were used as a starting point to obtain EU-wide data on investment costs per deep renovation component.

Eurostat was a source of data for HICP, which was used to correct PRIMES prices to the euro2024 level.

Publicly available data from national sources, especially from Croatian building renovation programmes that promote deep renovation of residential and non-residential (public) buildings were used to determine overall costs of deep renovation.

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Thank you for your attention!

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Thank You

Get in touch for more information!

Project coordinator – Jiří Karásek, SEVEn

All project reports will be available for download on the streamSAVE+ website **https://streamsaveplus.eu/**

And the platform

https://streamsaveplus.eu/priority-actions

Email the project at **jiri.karasek@svn.cz**

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