UNIVERSITÀ DEGLI STUDI FIRENZE

Energy consumption and greenhouse gas emissions in the wastewater treatment plant: a decision support system for planning and management

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NEW TREND AND RESEARCH PERSPECTIVE – TOWARDS A MORE SUSTAINABLE ENVIRONMENT

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Introduction

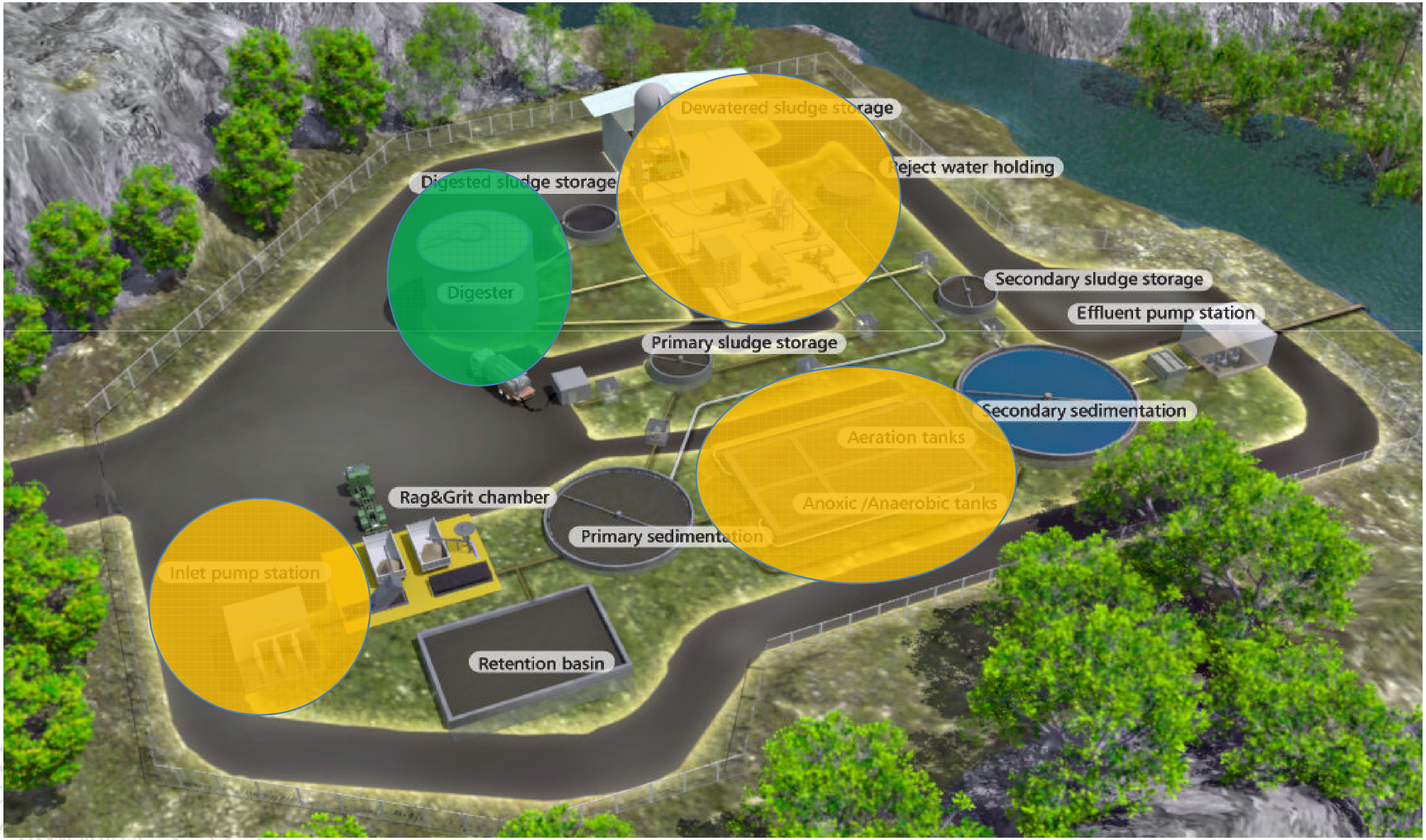
- Wastewater treatment plants (WWTPs) process on a daily basis large amounts of organic matter and nitrogen which are expected to increase in the future.

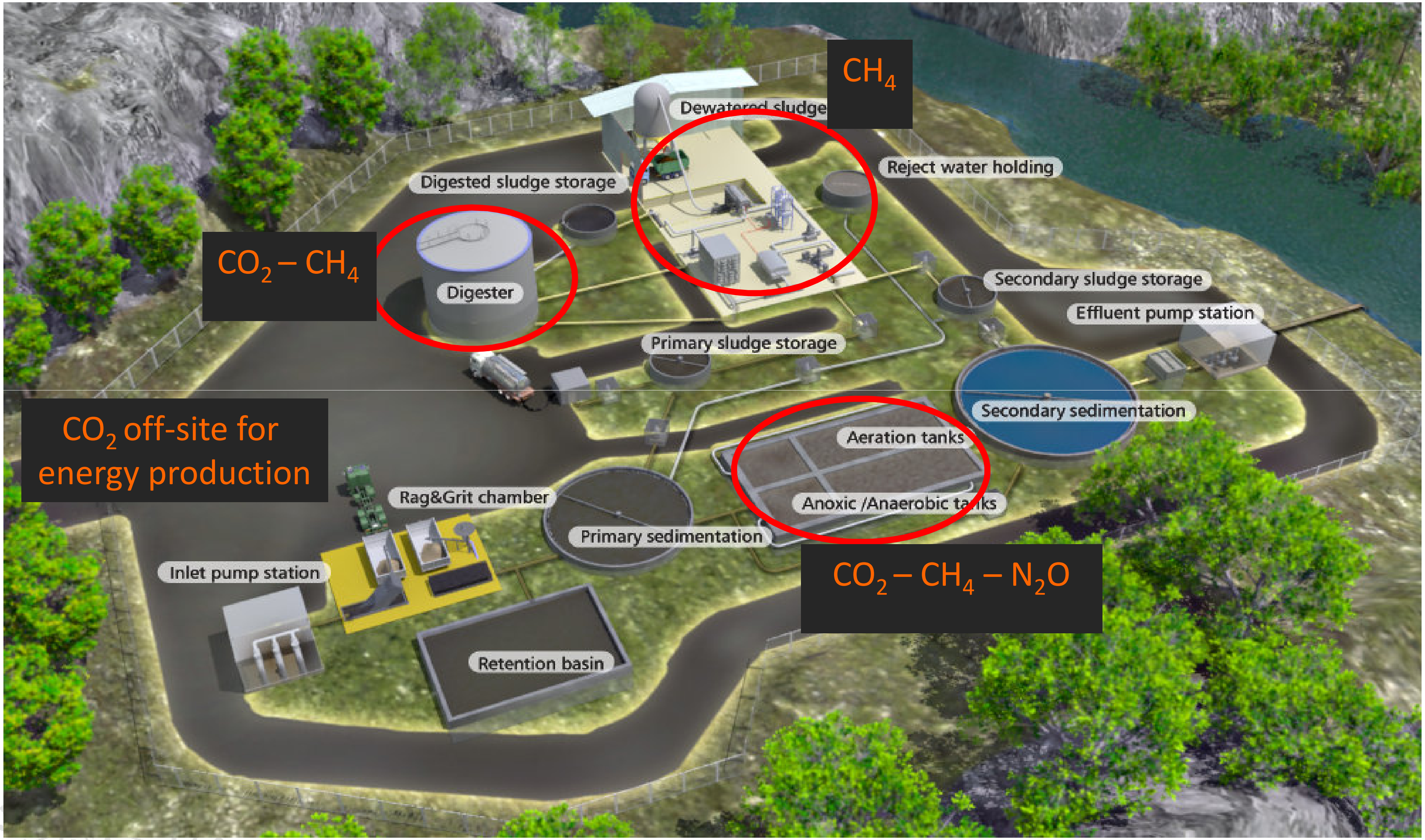
- WWTPs emit directly and indirectly, greenhouse gases (GHGs). Due to emerging concerns with climate change and GHGs emission, it is critical to understand and minimize the carbon- and energy- footprint (CFP and eFP respectively) for WW treatment processes.

- Carbon- and energy- footprint of WW treatment processes are correlated since energy used for wastewater treatment is recognized as a key constituent in carbon-footprint analyses.

- Non-CO_2 GHGs emission (i.e., CH_4, N_2O) in some cases may have a comparable weight on carbon-footprint during wastewater treatment

Activated sludge process (ASP) is the most widely used for WW treatment.




CH4
Dewatered sludge
Reject water holding
Digested sludge storage
CO2 – CH4
Digester
Secondary sludge storage
Effluent pump station
Primary sludge storage
Secondary sedimentation
CO2 off-site for
energy production
Aeration tanks
Anoxic /Anaerobic tanks
Rag&Grit chamber
Primary sedimentation
Inlet pump station
CO2 – CH4 – N2O
Retention basin

Introduction

GHGs emission and energy consumption of (AS) Wastewater treatment plants' (WWTPs), are affected by a great number of variables and mainly:

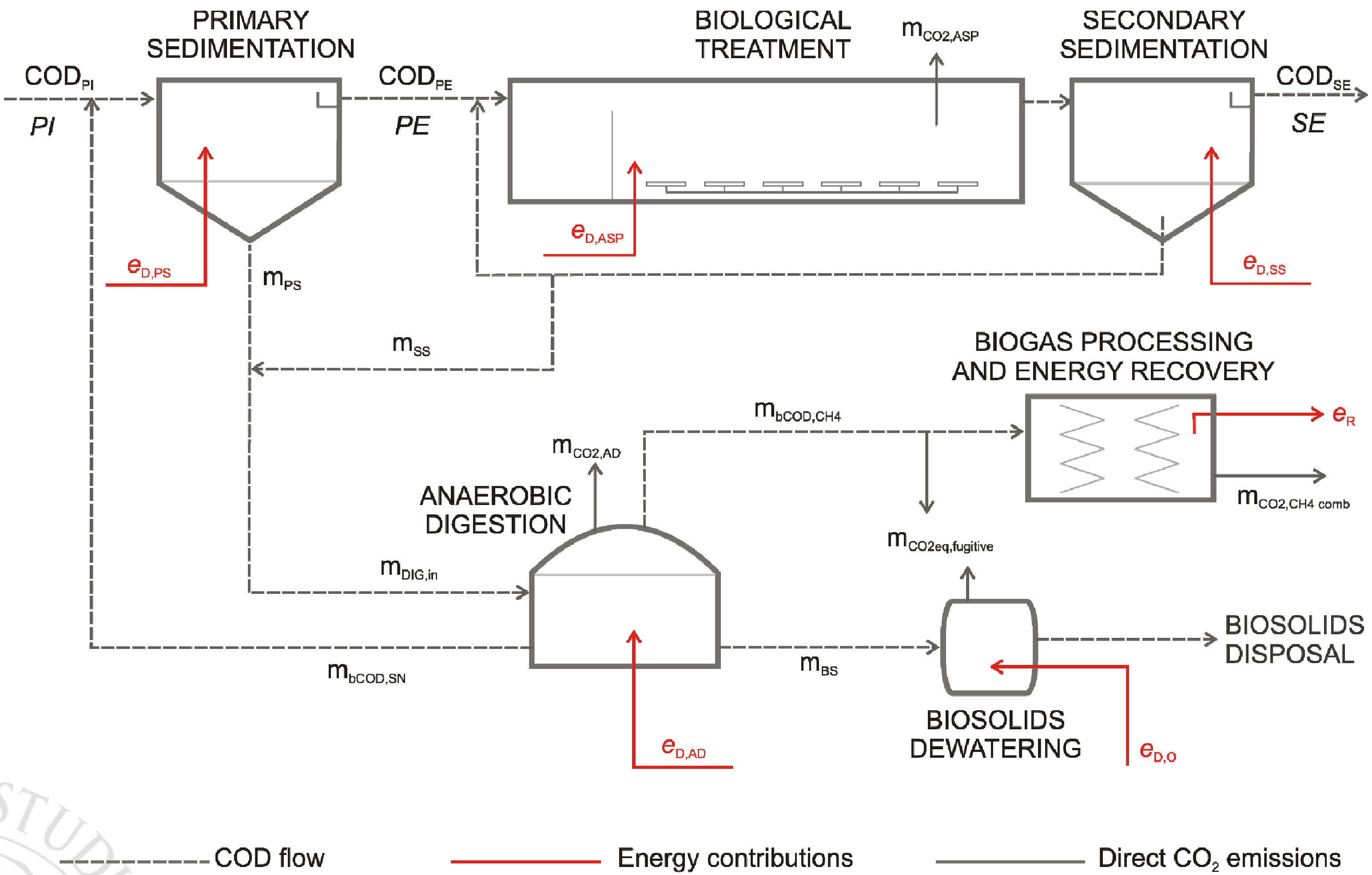
- sludge retention time (SRT) in the WW treatment train
- DO in aerobic tanks
- aeration efficiency
- HRT/SRT of sludge digestion
- wastewater and sludge treatment train
- characteristics of wastewater
- temperature in process tanks
- …

There is the need to properly model CFP, eFP and treatment costs of AS-WWTPs in order to set "optimal" operative conditions taking into account site specific characteristics

Model development

A dynamic model have been developed in order to analyze the effect of operative conditions, treatment train and site specific characteristics on CFP and eFP analysis.

Treatment train selected



Model structure (I)

- ASP model is based on ASM-family
- VSS is described in COD terms (depending on the pCOD/VSSvalue)
- AD is modeled with a simplified model which assume that hydrolysis is the limiting step for converting biodegradable components into methane

Hydrolysis: X_A, X_H, X_S, $X_{STO} \rightarrow S_S$

Methan formation from hydrolized compounds: $S_S \rightarrow CH_4$

Biogas composition: 65% CH_4 – 35%CO_2

Model structure (II): energy footprint

ENERGY DEMAND — PRIMARY SEDIMENTATION — ACTIVATED SLUDGE — SECONDARY SEDIMENTATION — ANAEROBIC DIGESTER — OTHER EQUIPMENT

$$e_D = e_{D,PS} + e_{D,ASP} + e_{D,SS} + e_{D,AD} + e_{D,O}$$

$$e_R = \eta_{ER} \cdot h_{BG} \cdot m_{BG}$$

ENERGY RECOVERY — EFFICIENCY OF ENERGY RECOVERY UNIT — BIOGAS CALORIC VALUE — BIOGAS PRODUCTION

$$eFP = e_D - e_R$$

Model structure (III)

- Carbon-equivalent footprint (CFP)
  - Only C-based emissions (CO_2, CH_4, power; no N_2O)
  - Assumes fixed power generation portfolio (i.e., constant $kg_{CO2,eq}/kWh$)

TOTAL $CO_{2,eq}$ EMISSION

DIRECT CO_2 FROM ASP RESPIRATION

DIRECT CO_2 FROM DIGESTER

DIRECT CO_2 FROM BIOGAS COMBUSTION

INDIRECT $CO_{2,eq}$ FROM POWER GENERATION

$CO_{2,eq}$ CREDIT OFFSET FROM ENERGY RECOVERY

DIRECT $CO_{2,eq}$ FROM FUGITIVE BIOGAS

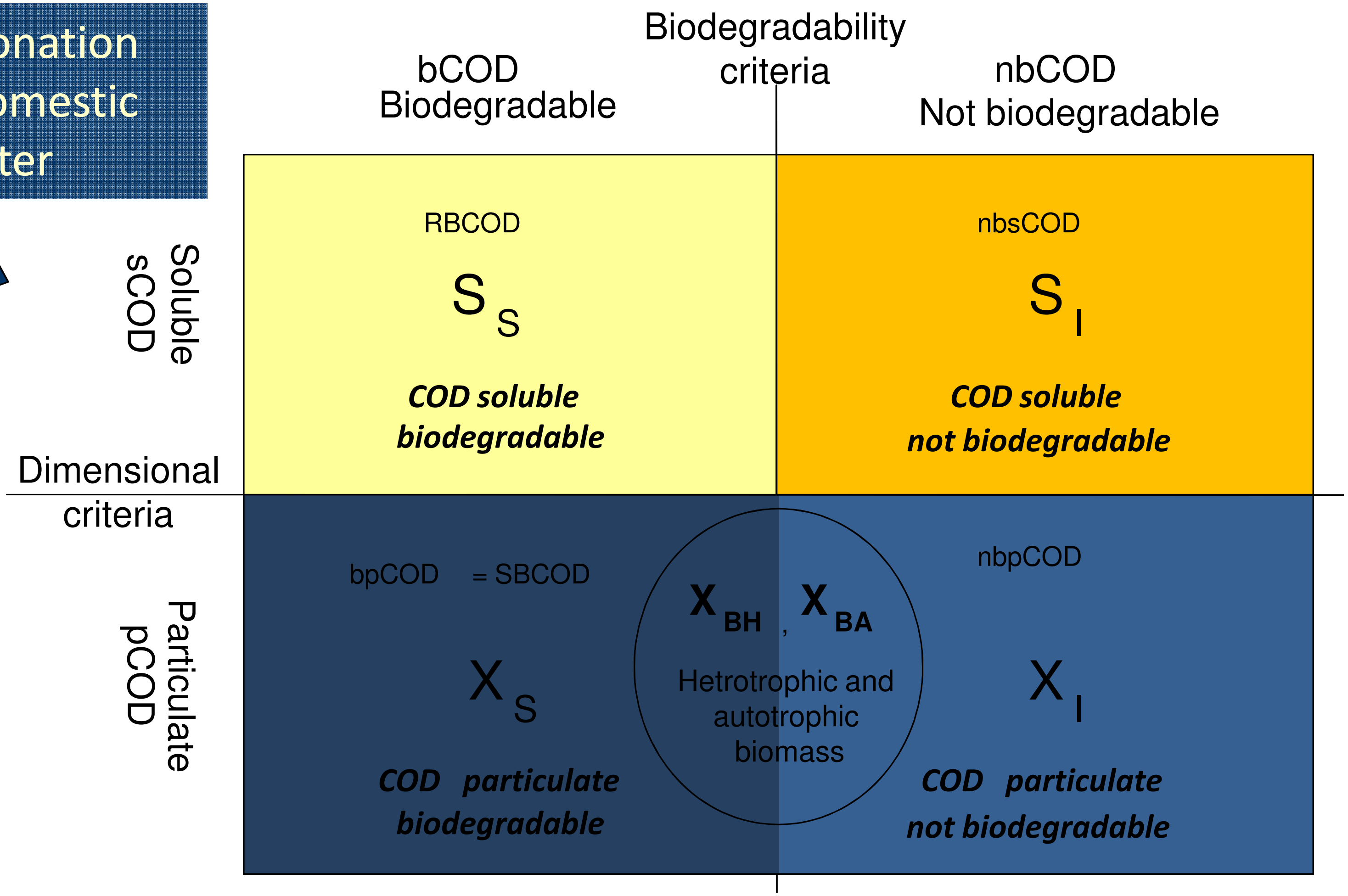
$$m_{CO_2eq} = m_{CO_2,ASP} + m_{CO_2,AD} + m_{CO_2,CH_4comb} + m_{CO_2eq,PG} - m_{CO_2eq,offset} + m_{CO_2eq,fugitive}$$

Effect of WW characteristics

- To show the **effect of varying COD and solids fractions on process carbon and energy footprints** using:
  - a simple rational procedure for COD and solids fractions quantification
  - a carbon and energy footprint models to quantify the effects of varying fractions on carbon-equivalent flows, process energy demand and recovery

COD fractionation

Typical fractionation criteria for domestic wastewater



COD an SS fractionation

Parameter	Symbol	ASM symbol	Formula
Particulate COD	pCOD	-	pCOD/VSS · VSS
Soluble COD	sCOD	-	COD - pCOD
Biodegradable COD	bCOD	-	$1,6 \cdot BOD_5$
Soluble non biodegradable COD	snbCOD	S_I^*	soluble COD of filtered SE
Soluble biodegradable COD	sbCOD	S_S	$sCOD - S_I$
Particulate biodegradable COD	pbCOD	X_S	$bCOD – S_S$
Particulate non biodegradable COD	pnbCOD	X_I^*	$pCOD - X_S$
Non biodegradable VSS	nbVSS	-	$pCOD/VSS \cdot X_I$
Biodegradable VSS	bVSS	-	$pCOD/VSS \cdot X_S$
Inert TSS	iTSS	-	TSS - VSS

Rationale

- **Different COD fractions have different fate** in the wastewater treatment train
  - sCOD ~ oxygen demand
  - pCOD ~ oxygen demand and/or energy recovery
- Not all particulate is created equal: **must transcend VSS definition**
- As a consequence, **different COD fractions** can **contribute differently to carbon** (CFP) **and energy footprint** (eFP) of the WWT process

The role of pCODS/VSS parameter

- Sludge sent to stabilization:

$$m_{pCOD,dig} = (pCOD/VSS)_{PS} \cdot m_{VSS,PS} + (pCOD/VSS)_{SS} \cdot m_{VSS,SS}$$

- $m_{pCOD,dig}$: COD MASS FLOW TO DIGESTER
- $(pCOD/VSS)_{PS}$: COD CONTENT OF PRIMARY VSS
- $m_{VSS,PS}$: MASS FLOW OF PRIMARY VSS
- $(pCOD/VSS)_{SS}$: COD CONTENT OF SECONDARY VSS
- $m_{VSS,SS}$: MASS FLOW OF SECONDARY VSS

- Once set the PS efficiency on SS removal, COD sent to AD depends on the ratio pCOD/VSS.

WWT Process used for model testing

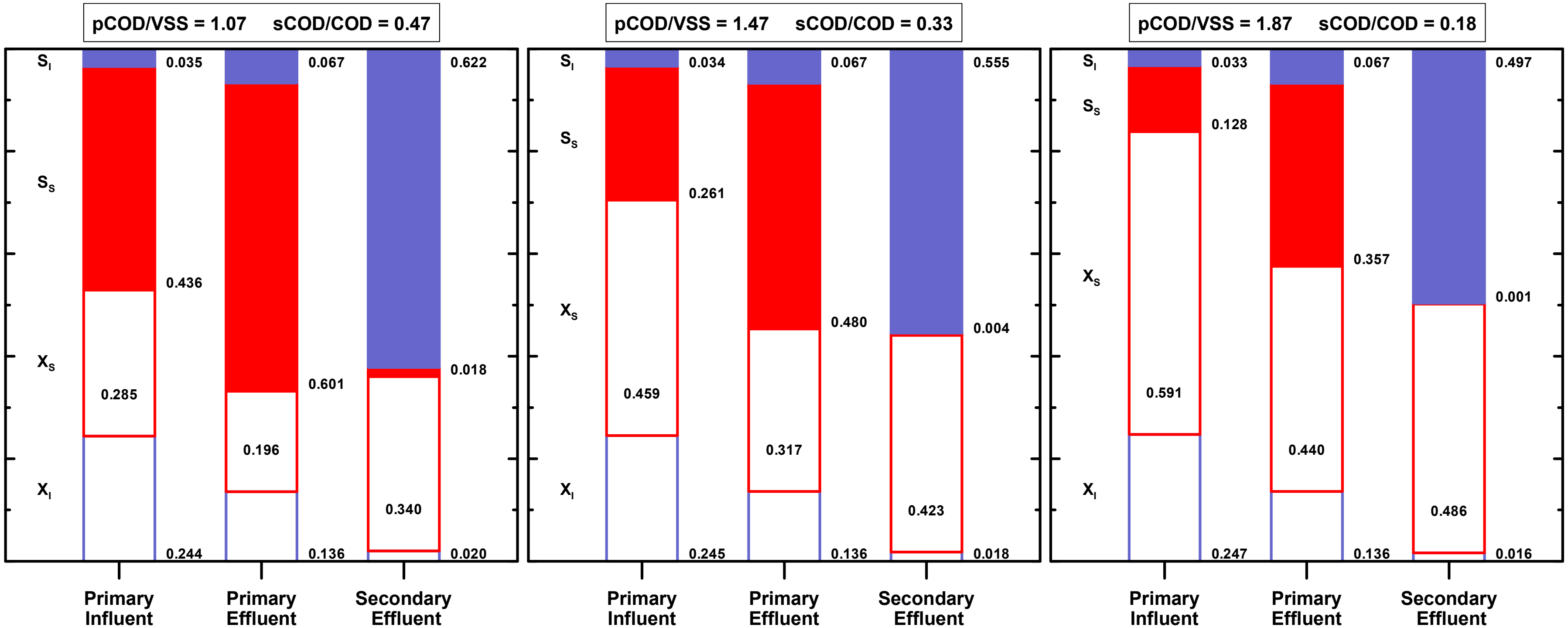
- 60.500 m^3/d (16MGD) water reclamation process
- Warm WW (19-27^{o}C)
- Influent grinder, followed by CEPT
- Flow equalization
- ASP MLE with MetOH addition
- MCRT = 6 - 10.5d
- Tertiary filtration and Cl_2 disinfection

Dataset: 1-year daily measurement of COD, BOD_5, VSS, TSS of influent, primary effluent and final effluent

The case of negative sCOD

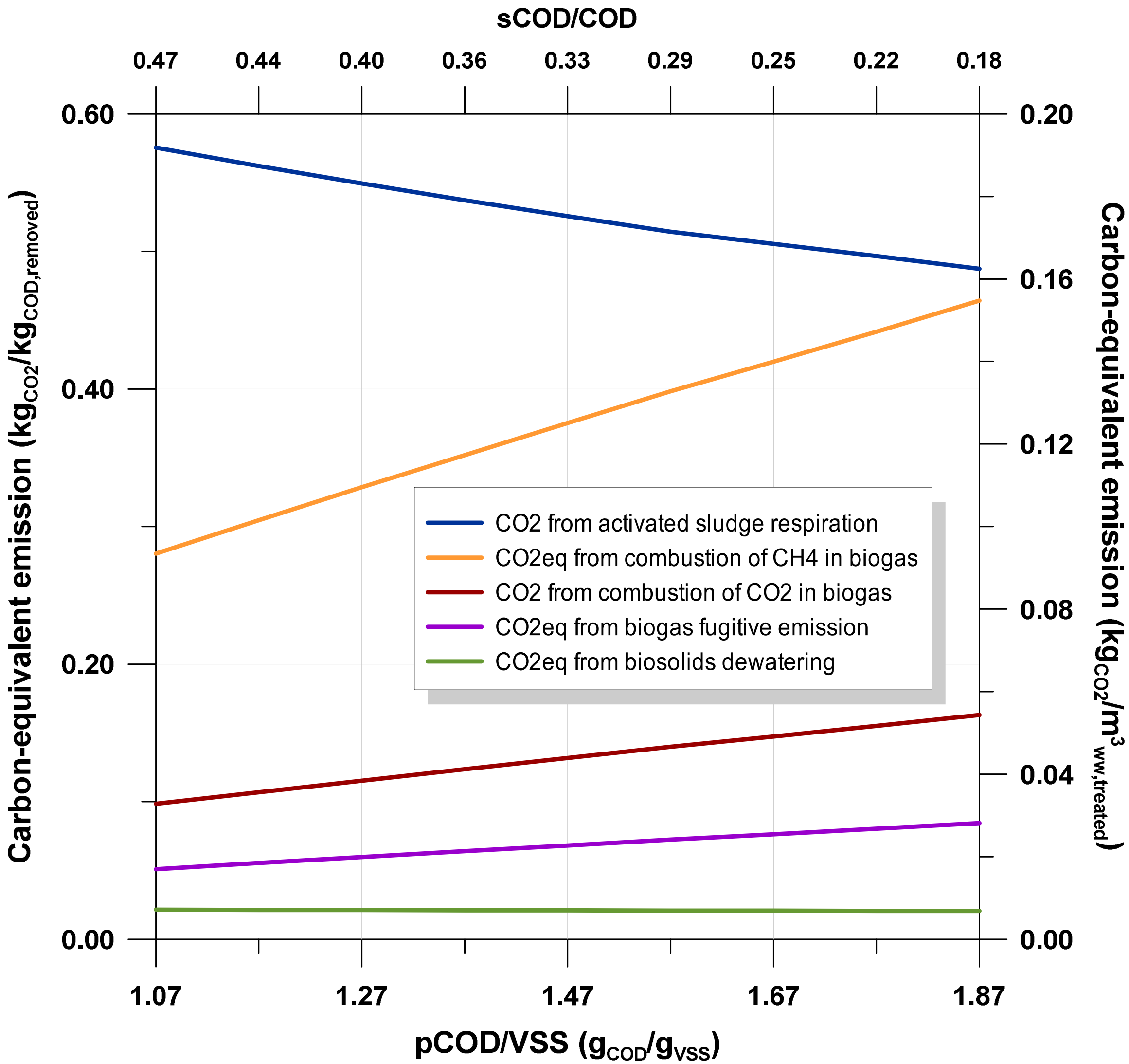
- **Possible** range pCOD/VSS = 1.07 – 2.87 (Takacs and Vanrolleghem, 2006)
- **Probable** range (raw municipal with minor industrial ww) pCOD/VSS = 1.22 – 1.50 (Henze and Comeau in IWA, 2008)
- Primary sludge pCOD/VSS = 1.40-1.62 (Ekama, 2009)
- Secondary sludge pCOD/VSS = 1.42 (M&E, 2003)
- Our model domain pCOD/VSS = 1.07-1.87 (26.2% sCOD<0)
- The rational procedure for COD fraction calculation fails (100% sCOD<0) for pCOD/VSS>2.59

Results – COD fractionation

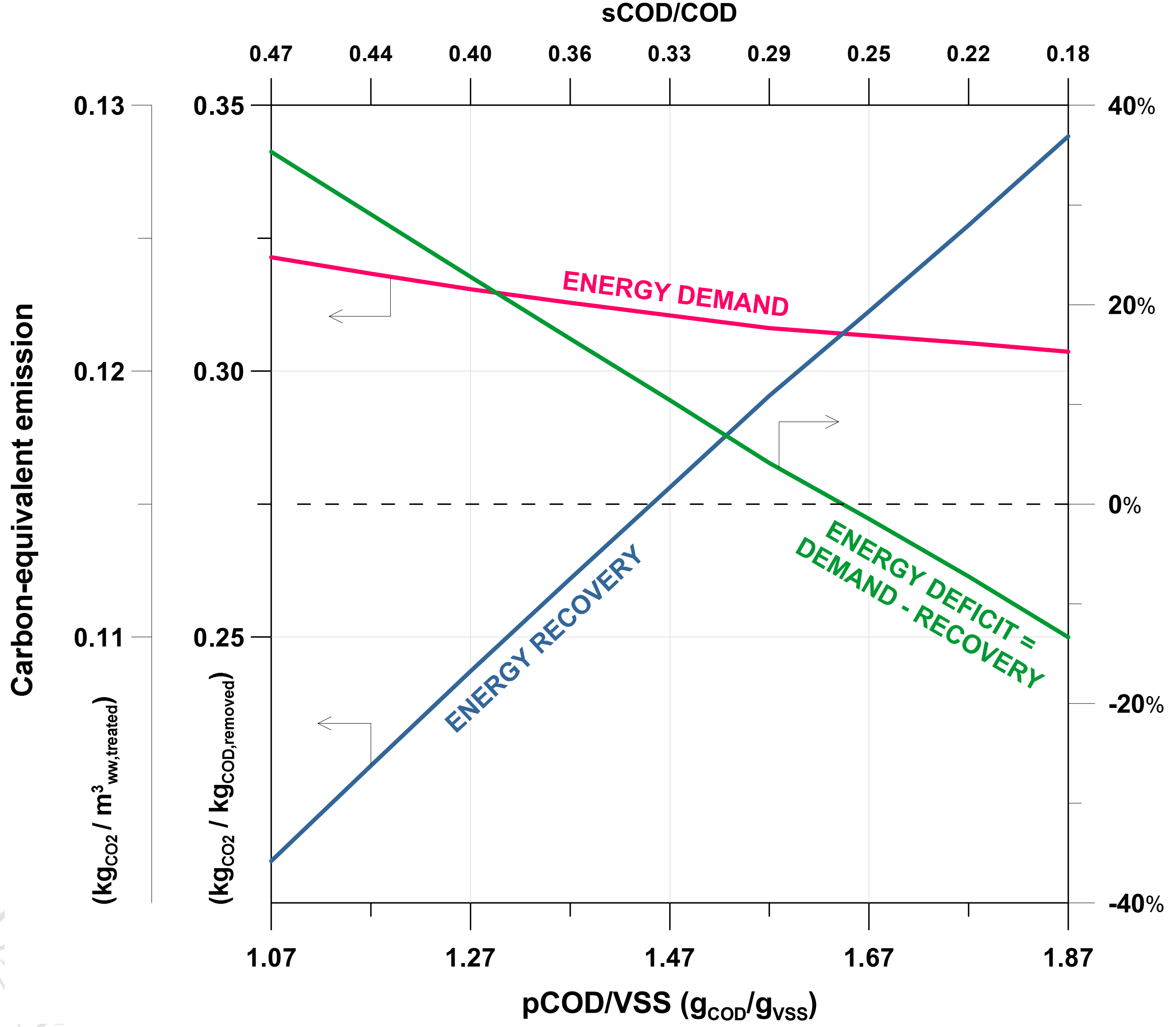


COD fractions for increasing pCOD/VSS ratios (average of 365d for each panel; 26.2% of cases due to negative sCOD)

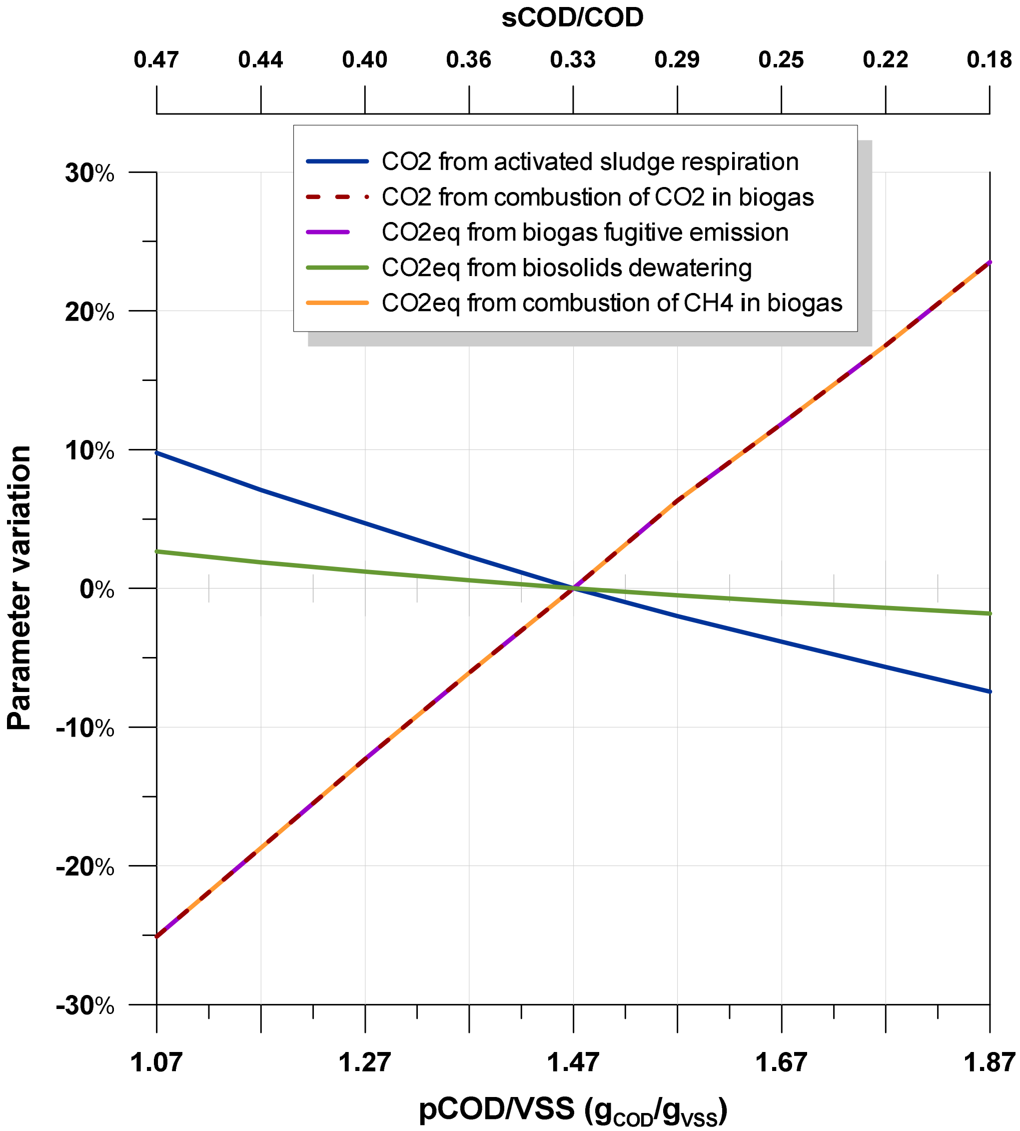
Results – CFP vs pCOD/VSS



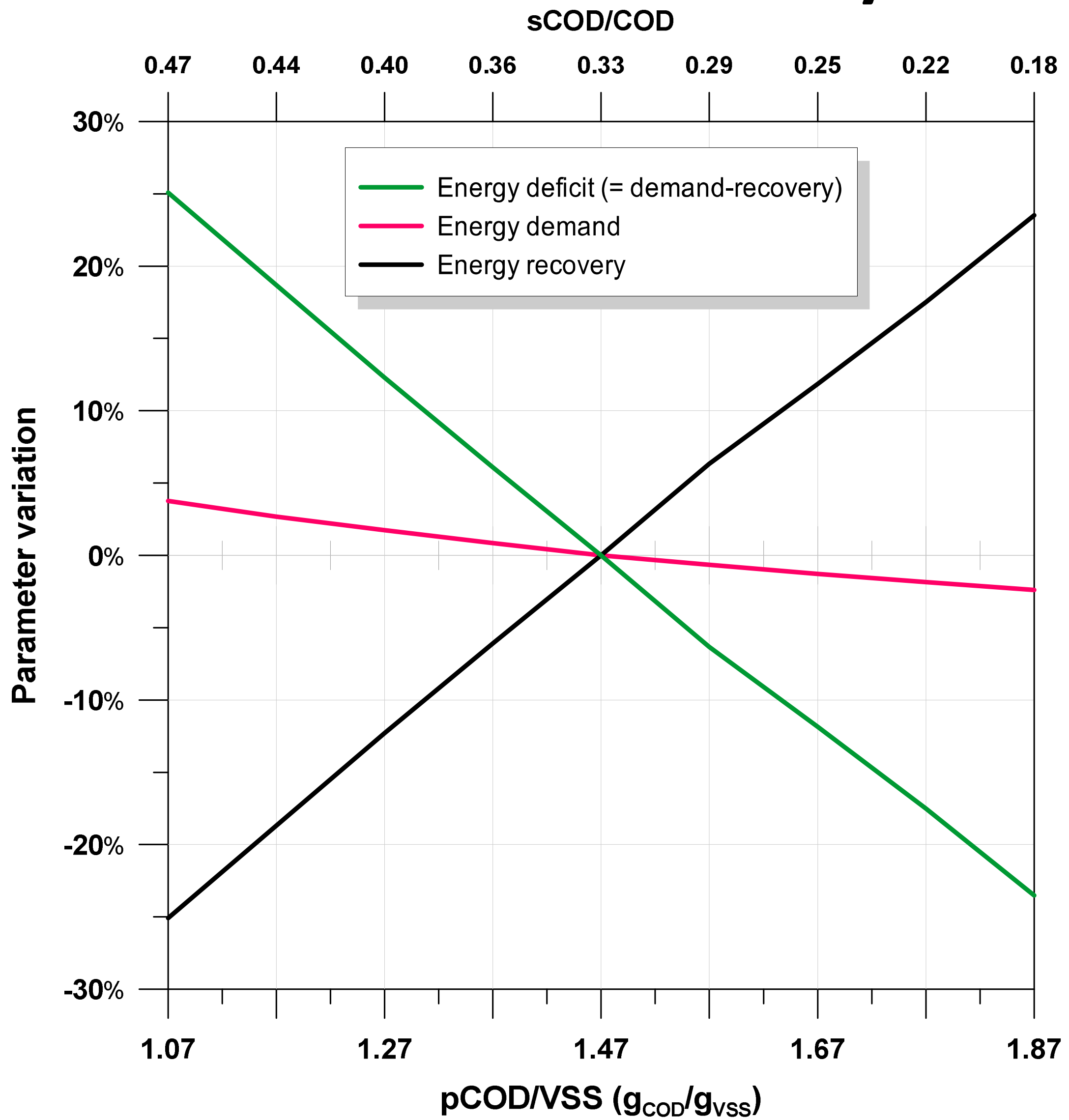
Results – eFP vs pCOD/VSS



Results – CFP Sensitivity analysis



Results – eFP Sensitivity analysis



Ministero dell'Istruzione Università e Ricerca

PRIN 2012

Programmi di Ricerca di Interesse Nazionale

Title of the project

Energy consumption and GreenHouse Gas (GHG) emissions in the wastewater treatment plants: a decision support system for planning and management

Duration: 3 years (03/2014 – 03/2017)

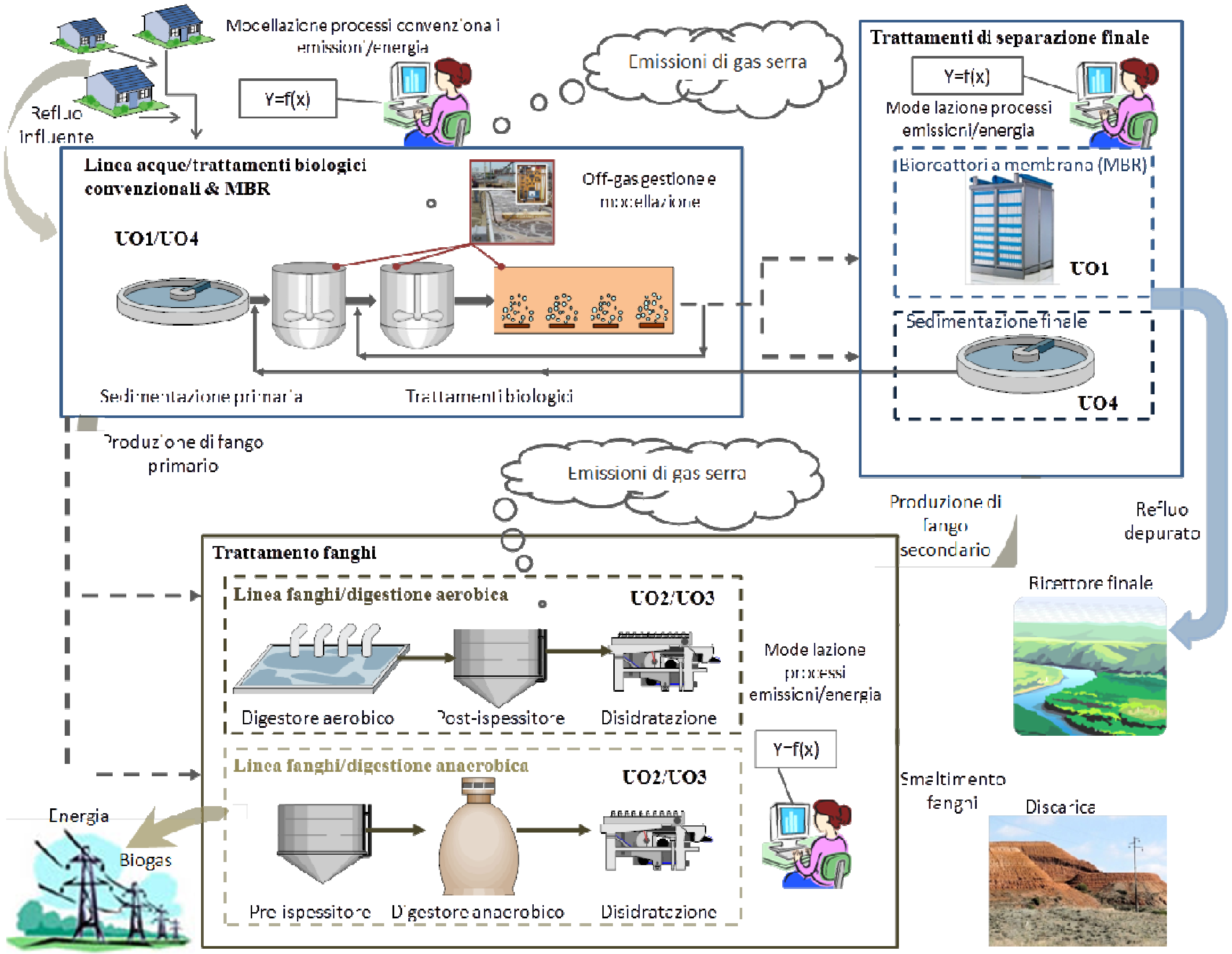
4 operative research units

Main scope of the project

- Development of an innovative tool for the design and management of WWTPs aimed at defining optimal setting up of WWTPs considering both single treatment units and their several interactions. The model will focus on both the energy consumption and the emissions.

- Setting-up of a protocol to measure GHGs from WWTPs with the final aim to set-up a standard protocol (still not available) which could be employed by both researchers and practitioners.

The research project



Thank you for your attention!

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