energies

Supplementary materials

Article

The feasibility of replacing coal with biomass in iron-ore pelletizing plants with respect to melt-induced slagging

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Section A_ Tables

Table S1. Chemical composition and calorimetric analysis of the solid biomasses[1, 2]

	Stem wood	Bark	Forest residue	Willow	Reed canary grass
Proximate analysis					
Water (wt %)	4.3	6.5	3.6	5.9	3.6
Ash (wt %, ds)	0.3	2.0	2.4	1.8	2.4
Ultimate analysis (wt %, ds)					
C	51.3	53.5	51.9	49.6	49.5
H	6.2	6.4	6.2	6.0	6.1
O	42.0	37.7	39.9	42.0	40.4
N	0.1	0.4	0.4	0.5	1.4
Cl	<0.02	<0.02	<0.02	<0.02	0.03
Inorganics (mg kg^{-1}, ds)					
Al	17.41	133.9	309.1	149.8	396.4
Ca	587.5	6197	2666	4603	2795
Fe	3.31	19.66	46.17	31.15	276.2
K	303.0	1444	1494	1610	1685
Mg	105.5	627.2	410.7	335.3	627.2
Mn	64.98	446.1	242.4	17.27	240.1
Na	23.22	118.7	112.8	109.8	79.38
P	25.66	358.7	312.5	467.0	1510
S	211.0	294.0	236.0	412.0	1340
Si	67.31	148.2	1262.	724.5	4062
Ti	0.60	2.34	13.31	7.37	11.87
Zn	8.73	123.0	48.90	54.70	61.20
Calorimetric analysis (MJ kg^{-1}, ds)					
Effective heating value	19.3	20.7	19.6	18.4	18.6

Table S2. Chemical composition and calorimetric analysis of the pyrolysis oils (PO)[1, 2]

	Stem wood	Bark	Forest residue	Willow	Reed canary grass
Proximate analysis					
Water (wt %)	17.7	24.8	20.7	20.3	17.5
Ash (wt %, ds)	<0.01	0.04	0.03	0.05	0.04
Ultimate analysis (wt %, ds)					
C	56.0	55.9	56.2	55.0	55.6
H	6.4	7.4	6.1	6.5	6.7
O	37.5	36.3	37.3	38.2	36.3
N	<0.1	0.3	0.4	0.3	1.4
Cl	0.009	-	-	-	-
Inorganics (mg kg^{-1}, ds)					
Al	0.77	<0.9	1.81	0.95	3.99
Ca	8.85	<11	17.44	37.92	42.98
Fe	1.25	1.56	2.85	2.53	12.13
K	13.49	23.27	51.57	63.63	45.59
Mg	<1.5	1.18	2.94	2.75	13.17
Mn	0.75	0.84	1.83	0.22	4.69
Na	<3	1.28	<3	<3	<4
P	2.90	2.92	5.50	7.23	33.43
S	116.4	122.4	125.7	157.3	790.3
Si	1.57	<9	2.53	2.31	11.07
Ti	<0.1	<0.5	<0.1	<0.1	0.153
Zn	1.51	5.09	3.65	2.86	4.02
Calorimetric analysis (MJ kg^{-1}, ds)					
Effective heating value	21.7	23.6	22.4	21.0	21.3

Table S3. Chemical composition and calorimetric analysis of the biochar[1, 2]

	Stem wood	Bark	Forest residue	Willow	Reed canary grass
Proximate analysis					
Water (wt %)	-	-	-	-	-
Ash (wt %, ds)	2.1	9.0	9.5	12.8	14.2
Ultimate analysis (wt %, ds)					
C	67.8	71.6	72.9	70.1	68.4
H	4.9	3.7	3.3	3.3	2.9
O	24.9	14.8	13.4	12.6	11.9
N	0.25	0.69	0.74	1.01	2.35
Cl	<0.02	<0.02	0.03	0.06	0.04
Inorganics (mg kg^{-1}, ds)					
Al	116.4	608.6	1683	730.4	725.1
Ca	4939	29020	20080	34160	16150
Fe	21.16	81.08	249.6	218.5	691.5
K	2341	7247	11950	12540	12700
Mg	892.5	2883	3160	2653	5204
Mn	563.8	2052	1928	123.1	1750
Na	204.0	514.9	626.1	656.5	257.4
P	214.3	1658	2483	3683	9339
S	243.0	236.0	248.0	1050	1290
Si	385.6	626.4	6077	3552	21740
Ti	3.78	9.95	67.75	31.59	30.87
Zn	50.50	562.0	317.0	394.0	458.0
Calorimetric analysis (MJ kg^{-1}, ds)					
Effective heating value	26.0	26.1	26.5	25.2	25.1

Table S4. The chemical composition of the coal and pellet-dust used in the TECs

Coal/Pellet-dust	Coal	Pellet-dust
Proximate analysis (wt.% as received)		
Volatile matter	21.2	-
Fixed carbon	62.2	-
Moisture	4.2	11.2
Ash content (coals)/minerals (pellet-dust)	12.4	88.8
Ultimate analysis (wt.% dry)		
C	76.4	-
H	4.0	-
N	1.39	-
O	5.1	30.60
Cl	0.01	<0.002
S	0.323	<0.001
Lower heating value (MJ/kg dry)	30.4	-
Major inorganic elements (wt.% dry fuel)		(wt.% dry)
Si	3.27	0.98
Al	2.09	0.12
Ca	0.22	0.33
Fe	0.40	66.91
K	0.07	0.03
Mg	0.05	0.90
Mn	0.00	0.06
Na	0.04	0.03
P	0.08	0.025
Ti	0.09	0.09

Table S5. List of the phases used in the equilibrium calculations in the system SiO_2-Al_2O_3-CaO-MgO- FeO-Fe_2O_3-Na_2O-K_2O

Name	Model	Composition/formula	Comments
oxide melt (slag)	modified associate species model	basic oxides + binary and ternary liquid species	+ all interactions between them
(K,Na)(Fe,Al)O_2_HT	Multi sub-lattice model using Compound Energy Formalism	$(Al^{3+},Si^{4+},Fe^{3+})_1(Na^{1+},K^{1+},Va)_1(O^{2-})_2$	high T phase Alk(Al, Fe)O_2
(K,Na)(Fe,Al)O_2_LT		$(Al^{3+},Si^{4+},Fe^{3+})_1(Na^{1+},K^{1+},Va)_1(O^{2-})_2$	high T phase Alk(Al, Fe)O_2
Corundum		$(Al^{3+},Fe^{3+})_2(O^{2-})_3$	Me_2O_3 phase
KAF4S3		$(Al^{3+},Fe^{3+})_4(K^{1+})_4(Si^{4+})_3(O^{2-})_{14}$	$(K,Na)_4Al_4Si_3O_{14}$ phase
Kaliophilite-HT		$(Al^{3+},Fe^{3+})_2(K^{1+}, Na^{1+})_2(Si^{4+})_2(O^{2-})_8$	HT phase $KFeSiO_4$-$KAlSiO_4$
Kaliophilite-LT		$(Al^{3+},Fe^{3+})_2(K^{1+}, Na^{1+})_2(Si^{4+})_2(O^{2-})_8$	LT phase $KFeSiO_4$-$KAlSiO_4$
Leucite		$(Al^{3+},Fe^{3+})_2(K^{1+})_2(Si^{4+})_4(O^{2-})_{12}$	Quaternary phase $KFeSi_2O_6$-$KAlSi_2O_6$
Nepheline		$(Al^{3+}, Si^{4+})_2(Va)_1(Na^{1+},K^{1+},Va)_1(O^{2-})_4$	(Na,K)$AlSiO_4$-LT
Carnegieite		$(Al^{3+}, Si^{4+})_2(Va)_1(Na^{1+},K^{1+},Va)_1(O^{2-})_4$	(Na,K)$AlSiO_4$-HT
$Fe_{12}K_2O_{19}$_S1	Stoichiometric compounds	$Fe_{12}K_2O_{19}$	-

References

1. Johansson, A.-C., et al., *Characterization of pyrolysis products produced from different Nordic biomass types in a cyclone pilot plant.* Fuel processing technology, 2016. **146**: p. 9-19.
2. Wiinikka, H., et al., *Fate of inorganic elements during fast pyrolysis of biomass in a cyclone reactor.* Fuel, 2017. **203**: p. 537-547.

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Section B_ Plots for the investigated raw biomasses

Description of the different plots:

1- Slag frac. & visc.: Mass fraction of the molten slag (melt) in the condensed phases predicted for the raw biomasses, together with the estimated viscosity of the respective molten slag. Color shading refers to the mass fraction of the predicted melt (slag fraction) and the iso-viscosity lines (contours) refer to the estimated viscosities of the respective melt fractions in Pa.s.

2- QSI: Calculated QSI values [where QSI = ln(1/μ), and μ is the viscosity of the molten fraction of the condensed phases] for the raw biomasses. Color shading refers to the calculated QSI.

3- B/A ratio: Calculated B/A absolute values as the ratio of network modifiers/ network formers for the raw biomasses. Color shading refers to the calculated absolute values (B/A).
The following equation is the ratio of “network modifiers” to “network formers”:

$$\frac{B}{A} = \frac{Network\ modifiers}{Network\ formers} = \frac{CaO+MgO+K_2O+Na_2O+Fe_2O_3+FeO}{SiO_2+Al_2O_3}$$

where SiO_2, etc., represent the mole fractions predicted for the major components in the respective predicted molten slags of the investigated fuels.

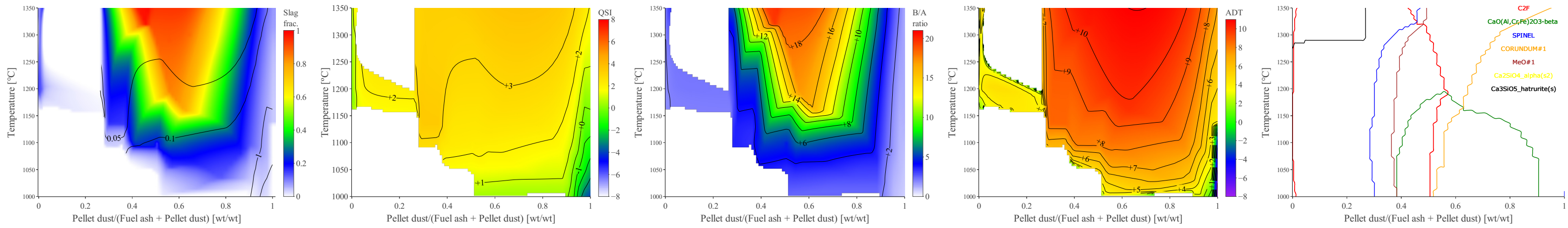
4- ADT: Plots of absolute deposition tendency (as defined in the manuscript) calculated for the raw biomasses.

5- Δ Slag frac. & visc.: Δ(slag frac.) values calculated for the TEC results of the raw biomasses under the definition, Δ(slag frac.) = $(\text{slag frac.})_{\text{raw biomass}}$ – $(\text{slag frac.})_{\text{ref}}$, where $(\text{slag frac.})_{\text{raw biomass}}$ and $(\text{slag frac.})_{\text{ref}}$ are mass fractions of the molten slag (melt) in the condensed phases calculated for the raw biomasses and the reference case (either coal or stem wood), respectively. The melt fractions predicted for the raw biomasses are less than the reference case (either coal or stem wood) if Δ(slag frac.) < 0, and higher if Δ(slag frac.) > 0. Color shading refers to the calculated Δ Slag frac.

6- Δ QSI: Δ(QSI) values calculated for the TEC results of the raw biomasses under the definition, Δ(QSI) = $(\text{QSI})_{\text{raw biomass}}$ – $(\text{QSI})_{\text{ref}}$, where $(\text{QSI})_{\text{raw biomass}}$ and $(\text{QSI})_{\text{ref}}$ are the calculated QSI values for the raw biomasses and the reference case (either coal or stem wood), respectively. The QSI calculated for the raw biomasses are less than the reference case (either coal or stem wood) if Δ(QSI) < 0, and higher if Δ(QSI) > 0. Color shading refers to the calculated ΔQSI.

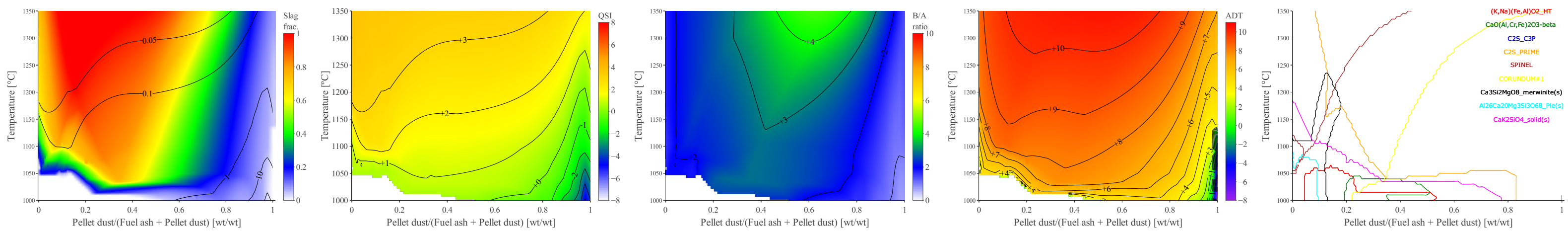
7- Δ B/A: Δ(B/A) values calculated for the TEC results of the raw biomasses under the definition, Δ(B/A) = $(\text{B/A})_{\text{raw biomass}}$ – $(\text{B/A})_{\text{ref}}$, where $(\text{B/A})_{\text{raw biomass}}$ and $(\text{B/A})_{\text{ref}}$ are the calculated B/A ratios for the raw biomasses and the reference case (either coal or stem wood), respectively. The B/A calculated for the raw biomasses are less than the reference case (either coal or stem wood) if Δ(B/A) < 0, and higher if Δ(B/A) > 0. Color shading refers to the calculated Δ B/A.

8- Δ ADT: Δ(ADT) values calculated for the TEC results of the raw biomasses under the definition, Δ(ADT) = $(\text{ADT})_{\text{raw biomass}}$ – $(\text{ADT})_{\text{ref}}$, where $(\text{ADT})_{\text{raw biomass}}$ and $(\text{ADT})_{\text{ref}}$ are the calculated ADTs for the raw biomasses and the reference case (either coal or stem wood), respectively. The ADT calculated for the raw biomasses are less than the reference case (either coal or stem wood) if Δ(ADT) < 0, and higher if Δ(ADT) > 0. Color shading refers to the calculated Δ ADT.



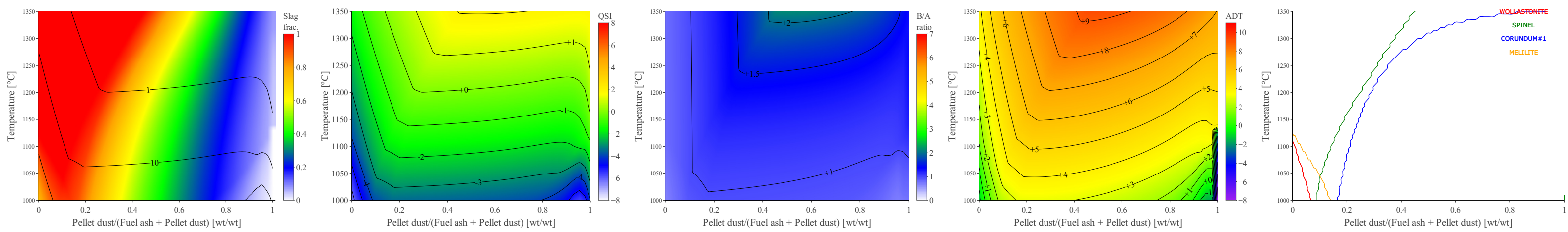
(a) Slag frac. & visc. (b) QSI (c) B/A ratio (d) ADT (e) Solid phases

Figure S1: Bark absolute plots



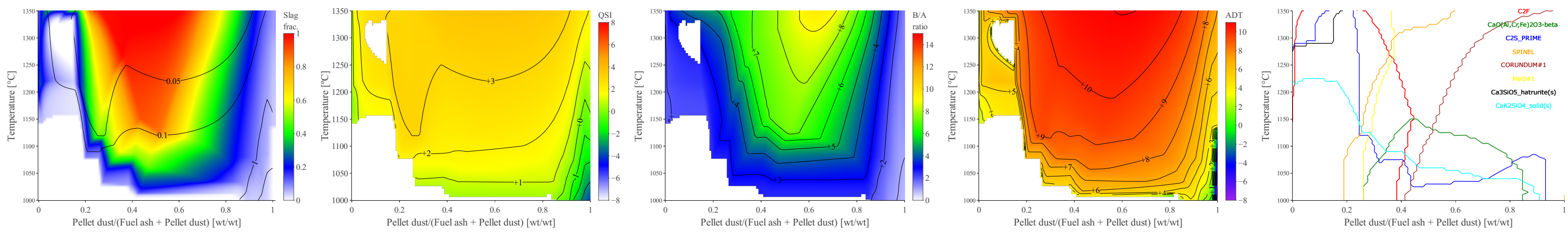
(a) Slag frac. & visc. (b) QSI (c) B/A ratio (d) ADT (e) Solid phases

Figure S2: Forest residue absolute plots



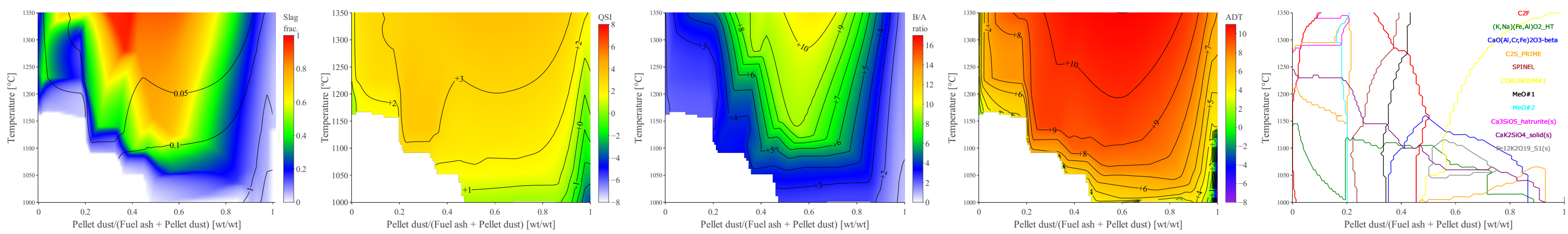
(a) Slag frac. & visc. (b) QSI (c) B/A ratio (d) ADT (e) Solid phases

Figure S3: Reed-Canary-grass absolute plots



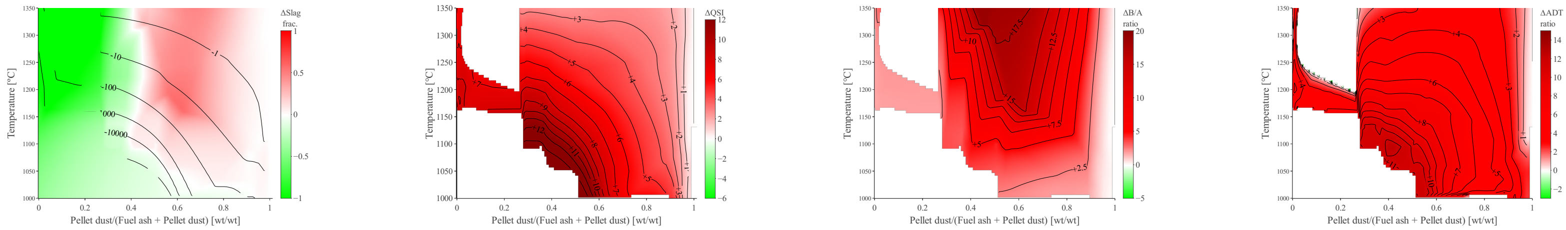
(a) Slag frac. & visc. (b) QSI (c) B/A ratio (d) ADT (e) Solid phases

Figure S4: Willow absolute plots



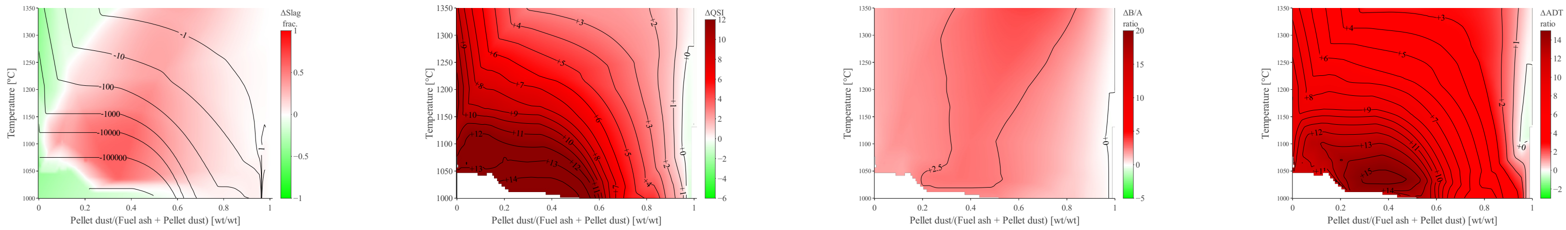
(a) Slag frac. & visc. (b) QSI (c) B/A ratio (d) ADT (e) Solid phases

Figure S5: Stemwood absolute plots



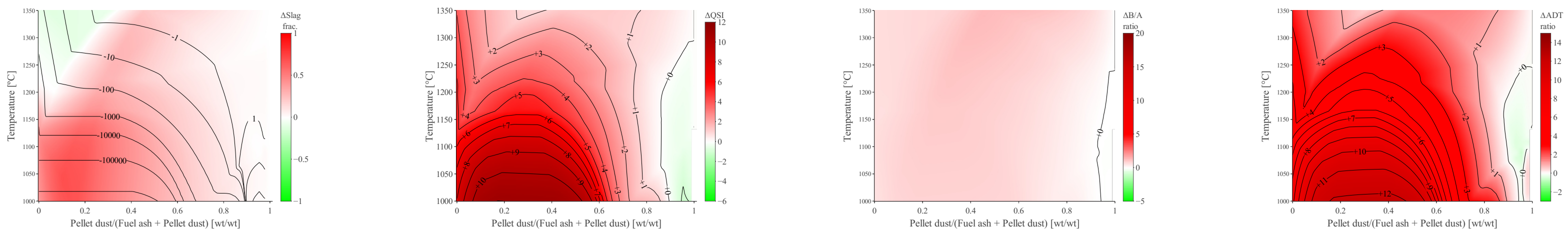
(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S6: Bark difference (coal reference) plots



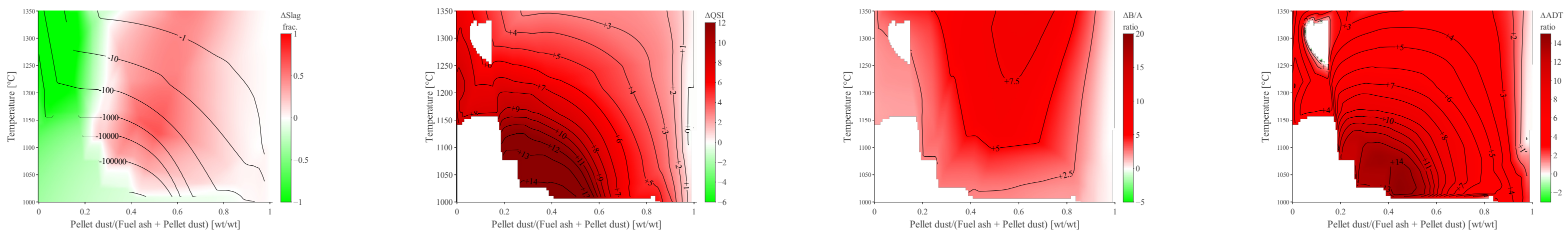
(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S7: Forest residue difference (coal reference) plots



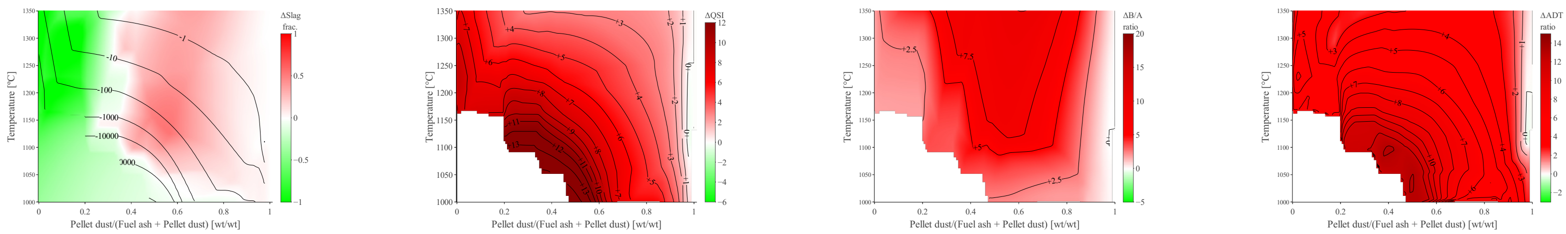
(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S8: Reed-Canary-grass difference (coal reference) plots



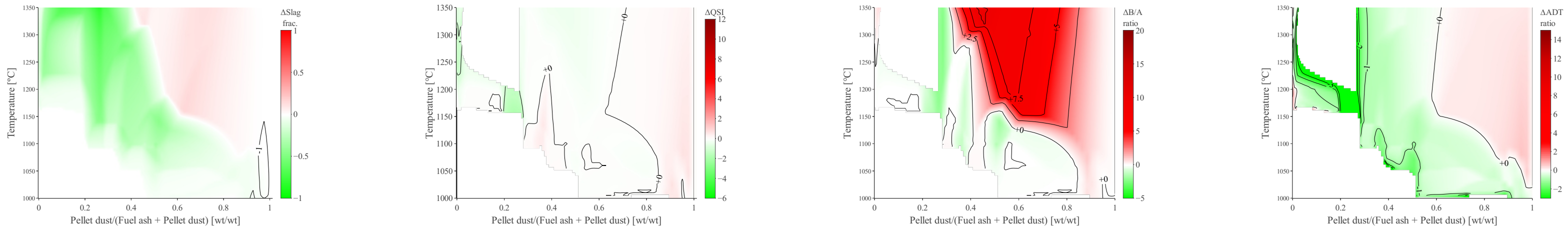
(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S9: Willow difference (coal reference) plots



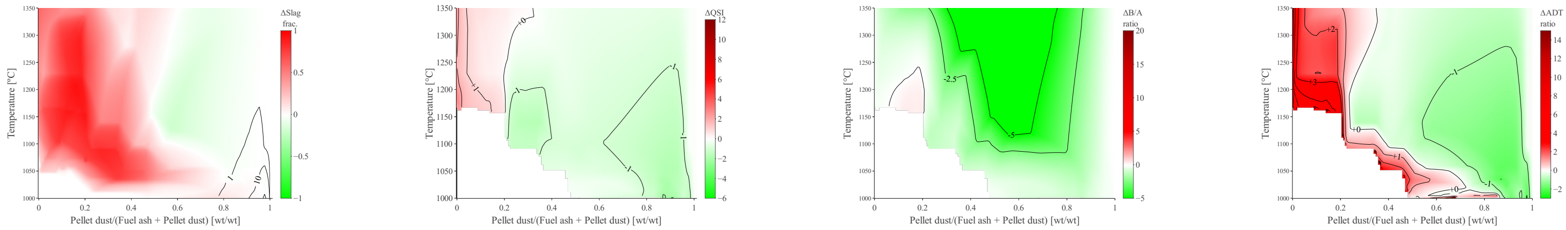
(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S10: Stemwood difference (coal reference) plots



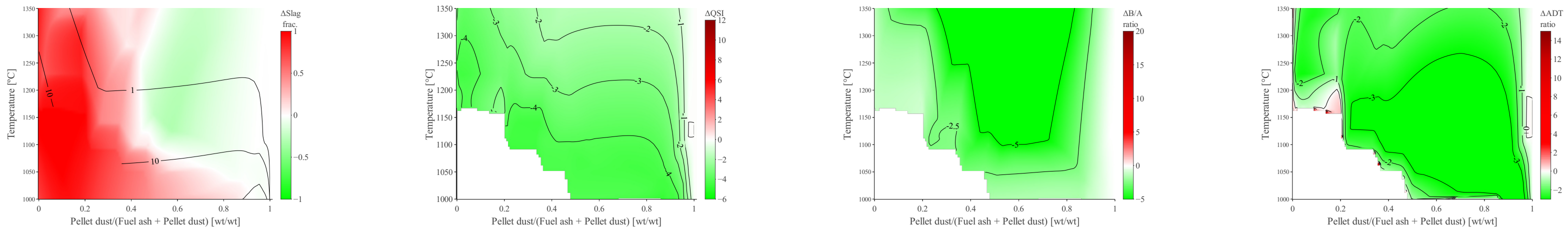
(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S11: Bark difference (Solid-Biomass stemwood reference) plots



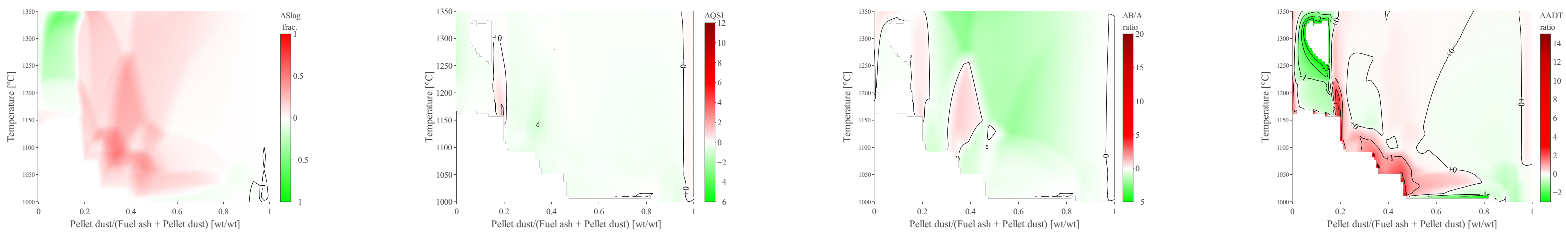
(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S12: Forest residue difference (Solid-Biomass stemwood reference) plots



(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S13: Reed-Canary-grass difference (Solid-Biomass stemwood reference) plots



(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

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Figure S14: Willow difference (Solid-Biomass stemwood reference) plots

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Section C_ Plots for the investigated pyrolysis oils (bio-oil)

Description of the different plots:

1- Slag frac. & visc.: Mass fraction of the molten slag (melt) in the condensed phases predicted for the pyrolysis oils (PO), together with the estimated viscosity of the respective molten slag. Color shading refers to the mass fraction of the predicted melt (slag fraction) and the iso-viscosity lines (contours) refer to the estimated viscosities of the respective melt fractions in Pa.s.

2- QSI: Calculated QSI values [where QSI = ln(1/μ), and μ is the viscosity of the molten fraction of the condensed phases] for the pyrolysis oils. Color shading refers to the calculated QSI.

3- B/A ratio: Calculated B/A absolute values as the ratio of network modifiers/ network formers for the pyrolysis oils. Color shading refers to the calculated absolute values (B/A).
The following equation is the ratio of "network modifiers" to "network formers":

$$\frac{B}{A} = \frac{Network\ modifiers}{Network\ formers} = \frac{CaO+MgO+K_2O+Na_2O+Fe_2O_3+FeO}{SiO_2+Al_2O_3}$$

where SiO_2, etc., represent the mole fractions predicted for the major components in the respective predicted molten slags of the investigated fuels.

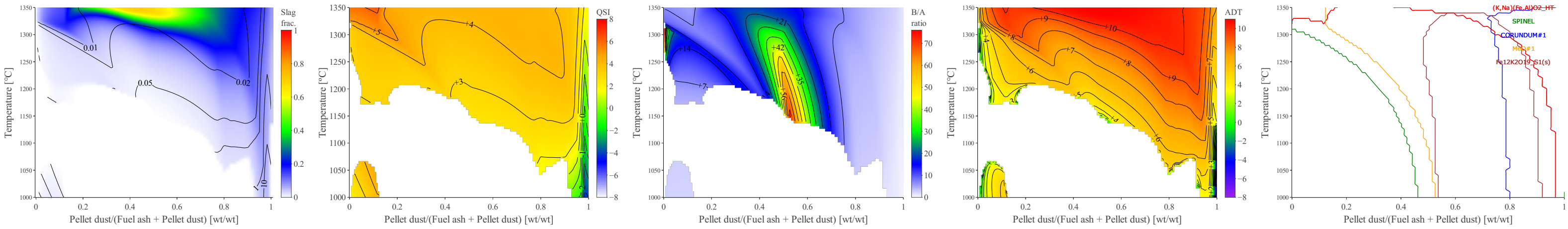
4- ADT: Plots of absolute deposition tendency (as defined in the manuscript) calculated for the pyrolysis oils.

5- Δ Slag frac. & visc.: Δ(slag frac.) values calculated for the TEC results of the pyrolysis oils under the definition, Δ(slag frac.) = $(\text{slag frac.})_{PO}$ – $(\text{slag frac.})_{ref}$, where $(\text{slag frac.})_{PO}$ and $(\text{slag frac.})_{ref}$ are mass fractions of the molten slag (melt) in the condensed phases calculated for the pyrolysis oils and the reference case (either coal or stem wood-PO), respectively. The melt fractions predicted for the pyrolysis oils are less than the reference case (either coal or stem wood-PO) if Δ(slag frac.) < 0, and higher if Δ(slag frac.) > 0. Color shading refers to the calculated Δ Slag frac.

6- Δ QSI: Δ(QSI) values calculated for the TEC results of the pyrolysis oils under the definition, Δ(QSI) = $(QSI)_{PO}$ – $(QSI)_{ref}$, where $(QSI)_{PO}$ and $(QSI)_{ref}$ are the calculated QSI values for the pyrolysis oils and the reference case (either coal or stem wood-PO), respectively. The QSI calculated for the pyrolysis oils are less than the reference case (either coal or stem wood-PO) if Δ(QSI) < 0, and higher if Δ(QSI) > 0. Color shading refers to the calculated ΔQSI.

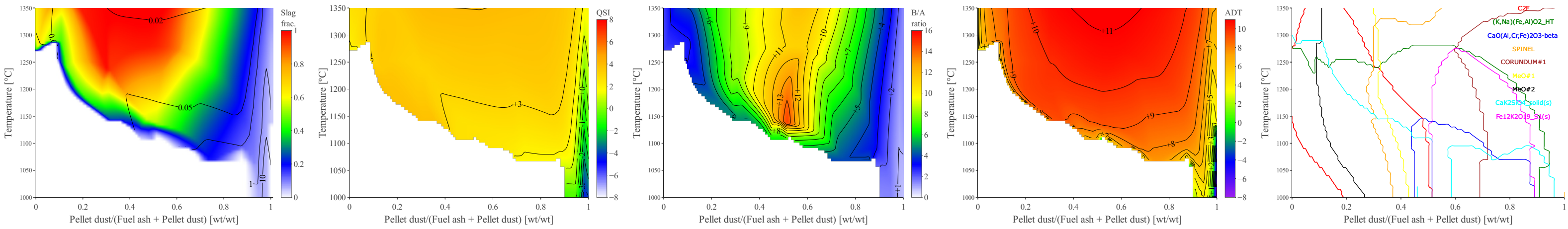
7- Δ B/A: Δ(B/A) values calculated for the TEC results of the pyrolysis oils under the definition, Δ(B/A) = $(B/A)_{PO}$ – $(B/A)_{ref}$, where $(B/A)_{PO}$ and $(B/A)_{ref}$ are the calculated B/A ratios for the pyrolysis oils and the reference case (either coal or stem wood-PO), respectively. The B/A calculated for the pyrolysis oils are less than the reference case (either coal or stem wood-PO) if Δ(B/A) < 0, and higher if Δ(B/A) > 0. Color shading refers to the calculated Δ B/A.

8- Δ ADT: Δ(ADT) values calculated for the TEC results of the pyrolysis oils under the definition, Δ(ADT) = $(ADT)_{PO}$ – $(ADT)_{ref}$, where $(ADT)_{PO}$ and $(ADT)_{ref}$ are the calculated ADTs for the pyrolysis oils and the reference case (either coal or stem wood-PO), respectively. The ADT calculated for the pyrolysis oils are less than the reference case (either coal or stem wood-PO) if Δ(ADT) < 0, and higher if Δ(ADT) > 0. Color shading refers to the calculated Δ ADT.



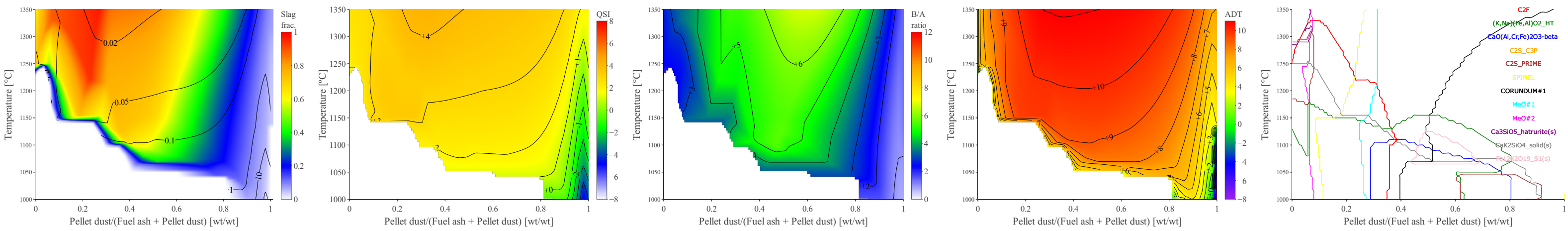
(a) Slag frac. & visc. (b) QSI (c) B/A ratio (d) ADT (e) Solid phases

Figure S15: Bark absolute plots



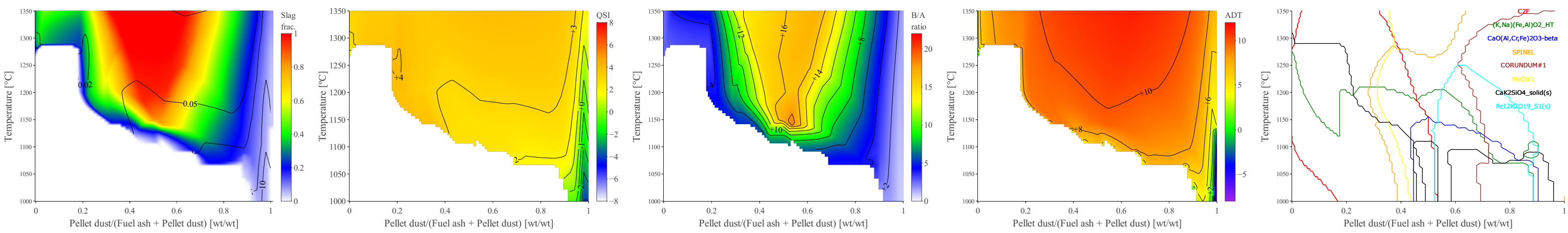
(a) Slag frac. & visc. (b) QSI (c) B/A ratio (d) ADT (e) Solid phases

Figure S16: Forest residue absolute plots



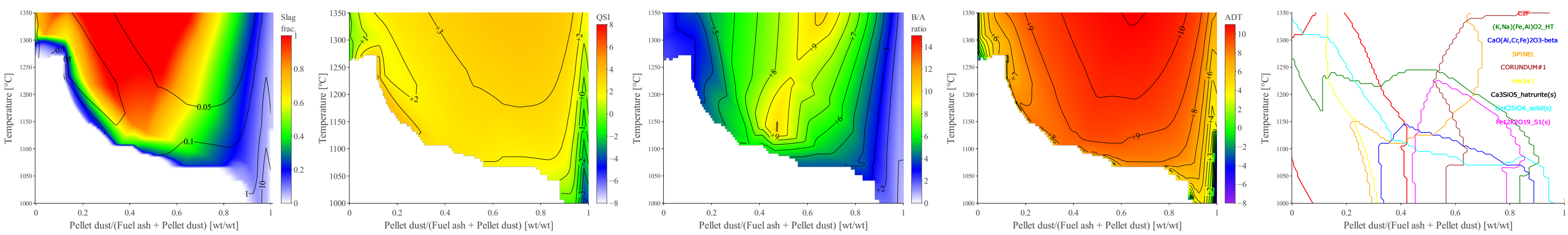
(a) Slag frac. & visc. (b) QSI (c) B/A ratio (d) ADT (e) Solid phases

Figure S17: Reed-Canary-grass absolute plots



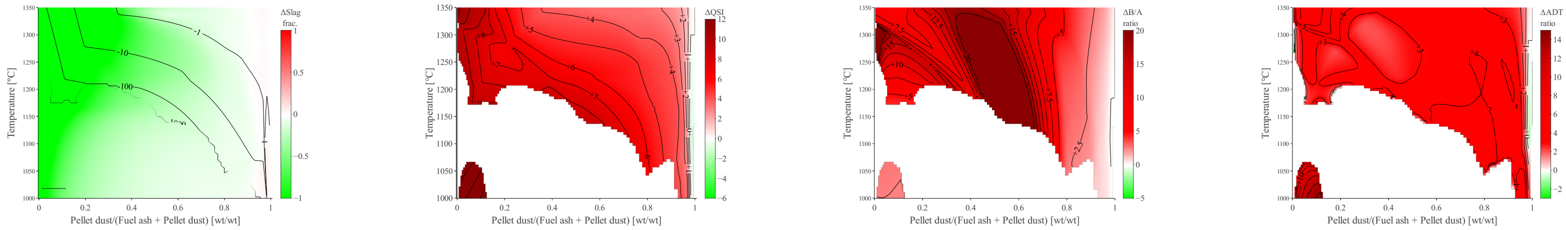
(a) Slag frac. & visc. (b) QSI (c) B/A ratio (d) ADT (e) Solid phases

Figure S18: Willow absolute plots



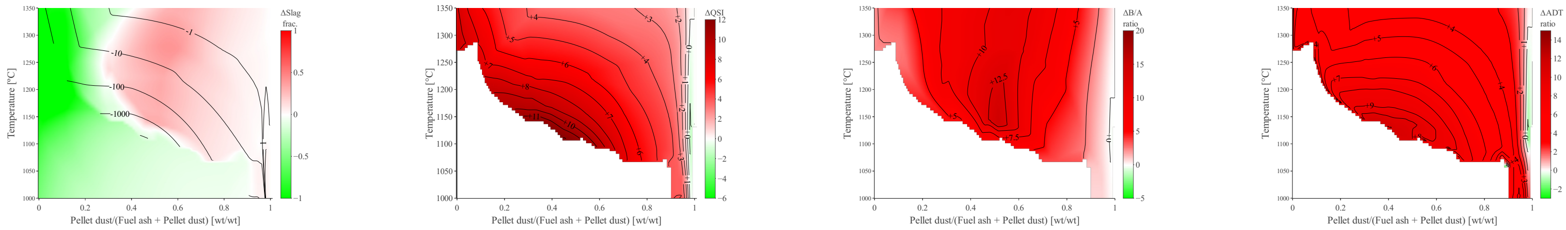
(a) Slag frac. & visc. (b) QSI (c) B/A ratio (d) ADT (e) Solid phases

Figure S19: Stemwood absolute plots



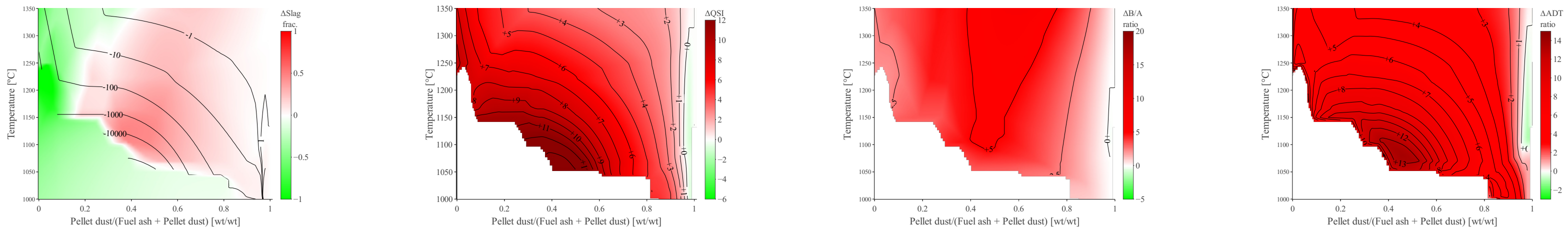
(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S20: Bark difference (coal reference) plots



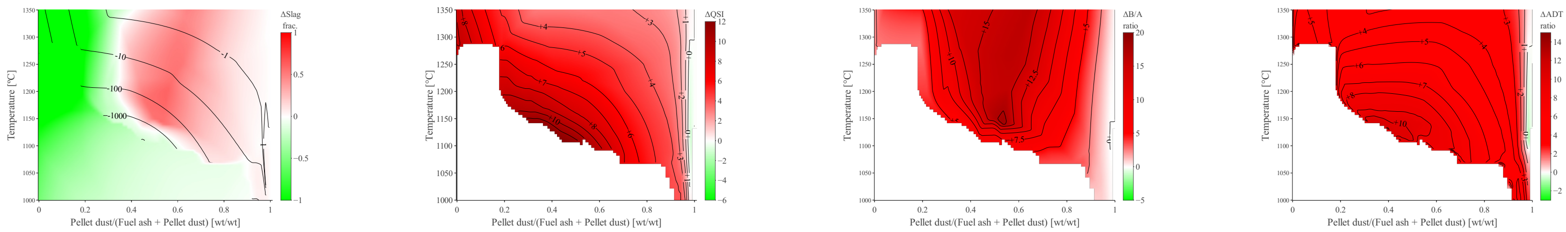
(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S21: Forest residue difference (coal reference) plots



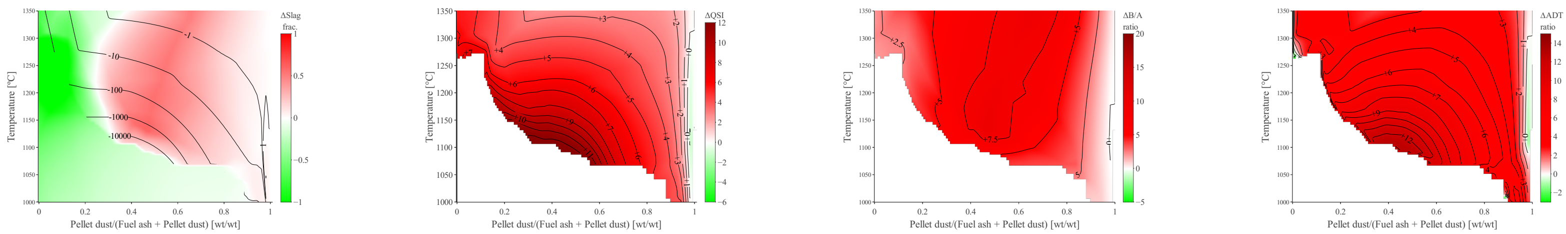
(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S22: Reed-Canary-grass difference (coal reference) plots



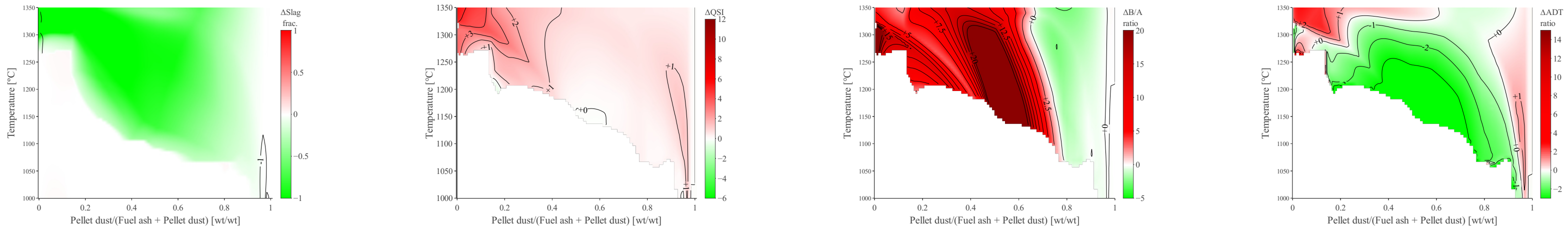
(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S23: Willow difference (coal reference) plots



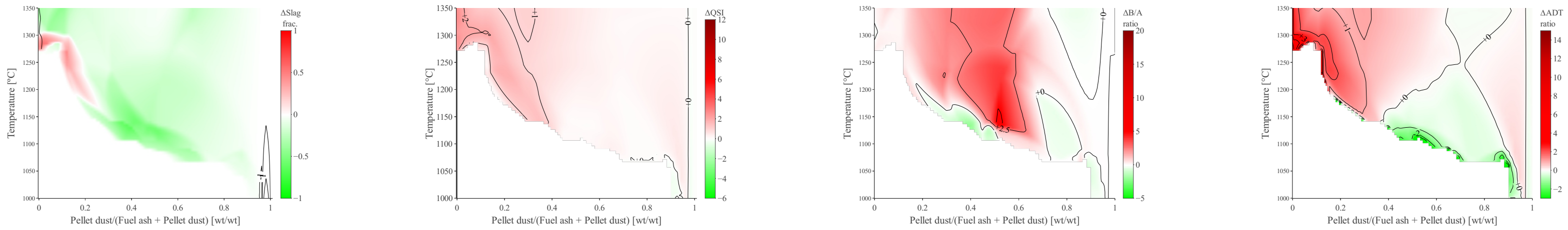
(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S24: Stemwood difference (coal reference) plots



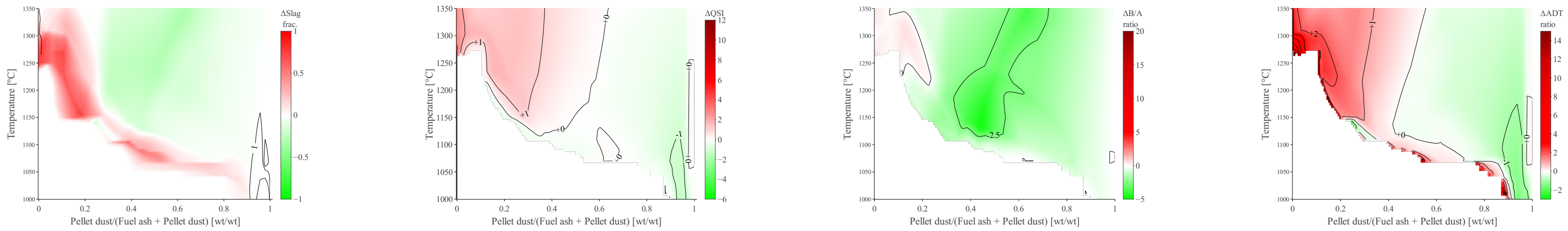
(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S25: Bark difference (PO stemwood reference) plots



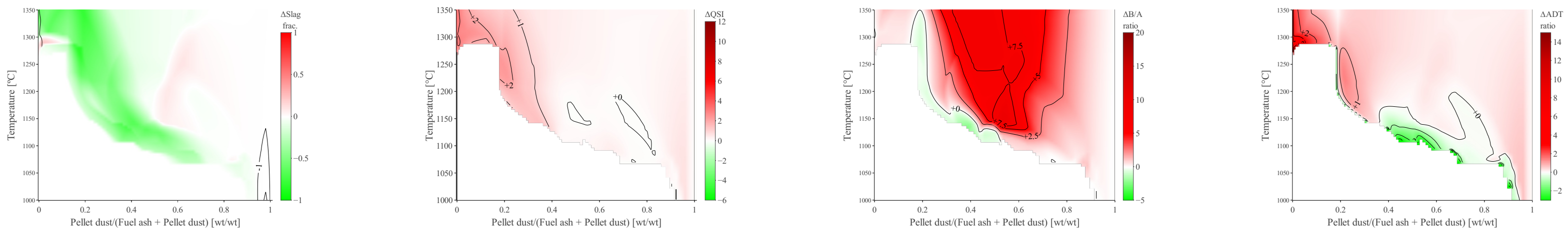
(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S26: Forest residue difference (PO stemwood reference) plots



(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S27: Reed-Canary-grass difference (PO stemwood reference) plots



(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S28: Willow difference (PO stemwood reference) plots

Section D_ Plots for the investigated biochars

Description of the different plots:

1- Slag frac. & visc.: Mass fraction of the molten slag (melt) in the condensed phases predicted for the biochars (BC), together with the estimated viscosity of the respective molten slag. Color shading refers to the mass fraction of the predicted melt (slag fraction) and the iso-viscosity lines (contours) refer to the estimated viscosities of the respective melt fractions in Pa.s.

2- QSI: Calculated QSI values [where QSI = ln(1/μ), and μ is the viscosity of the molten fraction of the condensed phases] for the biochars. Color shading refers to the calculated QSI.

3- B/A ratio: Calculated B/A absolute values as the ratio of network modifiers/ network formers for the biochars. Color shading refers to the calculated absolute values (B/A).

The following equation is the ratio of "network modifiers" to "network formers":

$$\frac{B}{A} = \frac{Network\ modifiers}{Network\ formers} = \frac{CaO+MgO+K_2O+Na_2O+Fe_2O_3+FeO}{SiO_2+Al_2O_3}$$

where SiO_2, etc., represent the mole fractions predicted for the major components in the respective predicted molten slags of the investigated fuels.

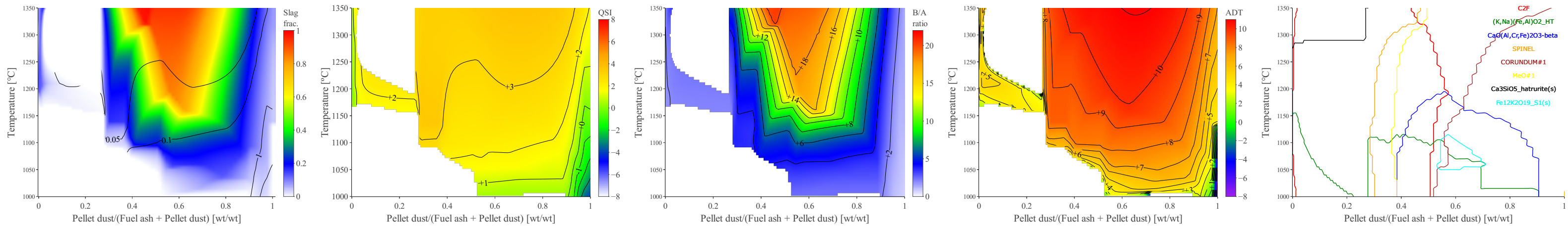
4- ADT: Plots of absolute deposition tendency (as defined in the manuscript) calculated for the biochars.

5- Δ Slag frac. & visc.: Δ(slag frac.) values calculated for the TEC results of the biochars under the definition, Δ(slag frac.) = $(\text{slag frac.})_{BC}$ – $(\text{slag frac.})_{ref}$, where $(\text{slag frac.})_{BC}$ and $(\text{slag frac.})_{ref}$ are mass fractions of the molten slag (melt) in the condensed phases calculated for the biochars and the reference case (either coal or stem wood-biochar), respectively. The melt fractions predicted for the biochars are less than the reference case (either coal or stem wood-biochar) if Δ(slag frac.) < 0, and higher if Δ(slag frac.) > 0. Color shading refers to the calculated Δ Slag frac.

6- Δ QSI: Δ(QSI) values calculated for the TEC results of the biochars under the definition, Δ(QSI) = $(QSI)_{BC}$ – $(QSI)_{ref}$, where $(QSI)_{BC}$ and $(QSI)_{ref}$ are the calculated QSI values for the biochars and the reference case (either coal or stem wood-biochar), respectively. The QSI calculated for the biochars are less than the reference case (either coal or stem wood-biochar) if Δ(QSI) < 0, and higher if Δ(QSI) > 0. Color shading refers to the calculated ΔQSI.

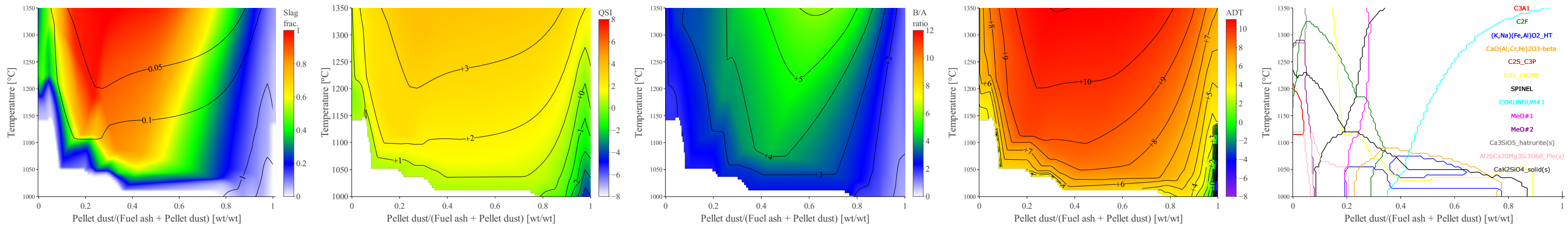
7- Δ B/A: Δ(B/A) values calculated for the TEC results of the biochars under the definition, Δ(B/A) = $(B/A)_{BC}$ – $(B/A)_{ref}$, where $(B/A)_{BC}$ and $(B/A)_{ref}$ are the calculated B/A ratios for the biochars and the reference case (either coal or stem wood-biochar), respectively. The B/A calculated for the biochars are less than the reference case (either coal or stem wood-biochar) if Δ(B/A) < 0, and higher if Δ(B/A) > 0. Color shading refers to the calculated Δ B/A.

8- Δ ADT: Δ(ADT) values calculated for the TEC results of the biochars under the definition, Δ(ADT) = $(ADT)_{BC}$ – $(ADT)_{ref}$, where $(ADT)_{BC}$ and $(ADT)_{ref}$ are the calculated ADTs for the biochars and the reference case (either coal or stem wood-biochar), respectively. The ADT calculated for the biochars are less than the reference case (either coal or stem wood-biochar) if Δ(ADT) < 0, and higher if Δ(ADT) > 0. Color shading refers to the calculated Δ ADT.



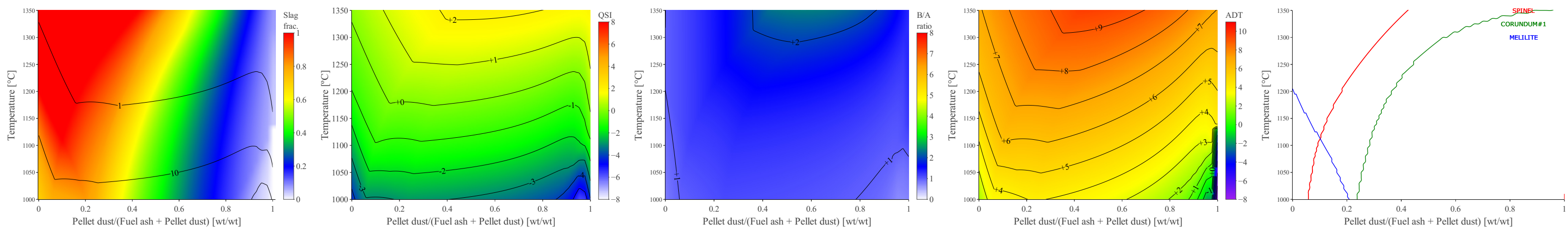
(a) Slag frac. & visc. (b) QSI (c) B/A ratio (d) ADT (e) Solid phases

Figure S29: Bark absolute plots



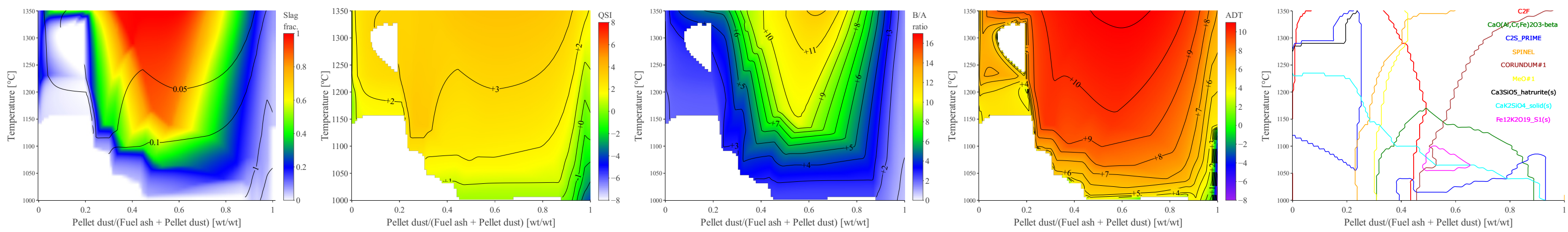
(a) Slag frac. & visc. (b) QSI (c) B/A ratio (d) ADT (e) Solid phases

Figure S30: Forest residue absolute plots



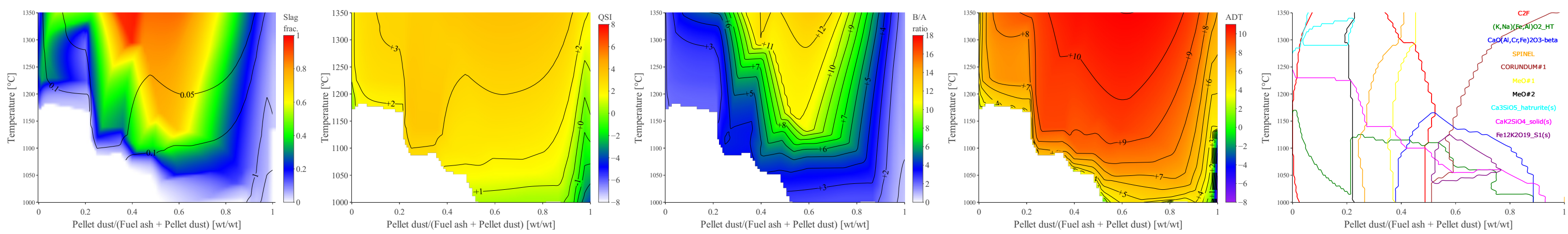
(a) Slag frac. & visc. (b) QSI (c) B/A ratio (d) ADT (e) Solid phases

Figure S31: Reed-Canary-grass absolute plots



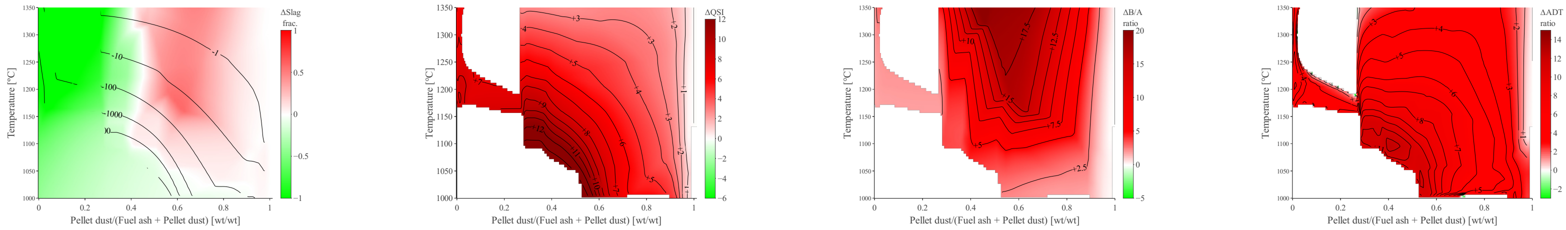
(a) Slag frac. & visc. (b) QSI (c) B/A ratio (d) ADT (e) Solid phases

Figure S32: Willow absolute plots



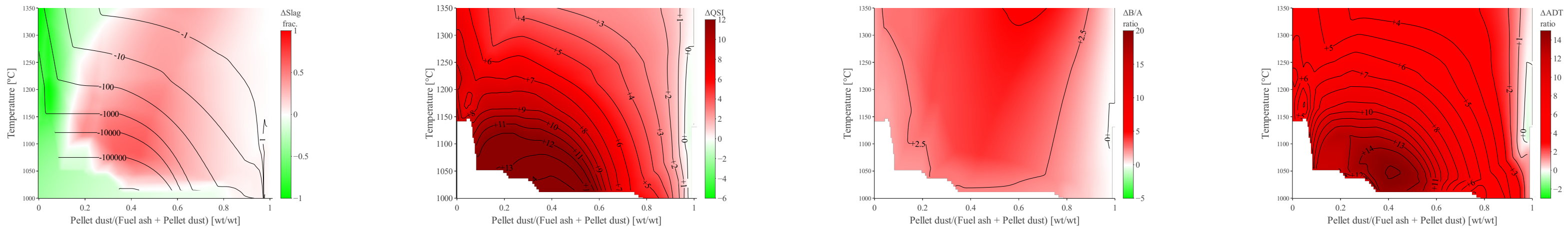
(a) Slag frac. & visc. (b) QSI (c) B/A ratio (d) ADT (e) Solid phases

Figure S33: Stemwood absolute plots



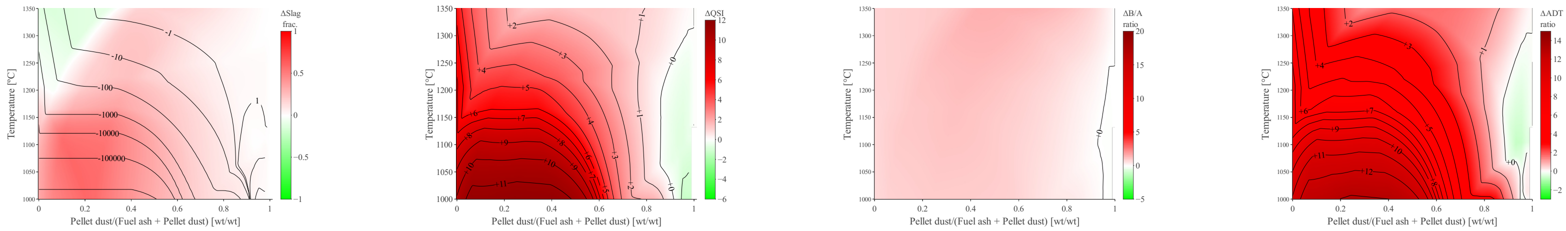
(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S34: Bark difference (coal reference) plots



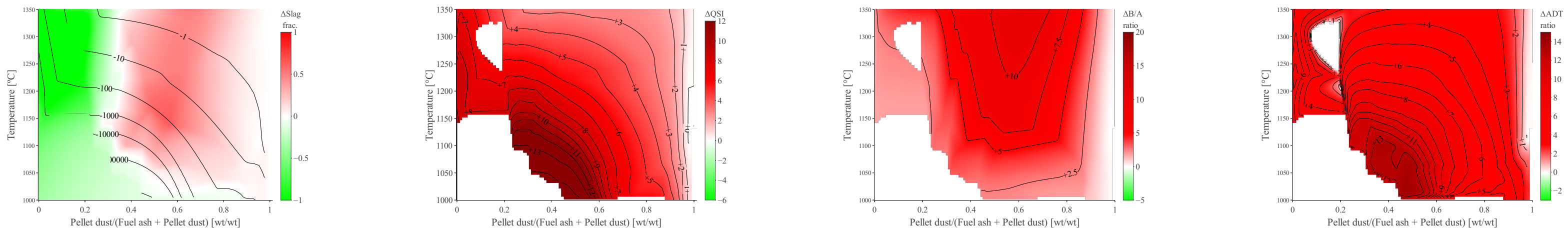
(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S35: Forest residue difference (coal reference) plots



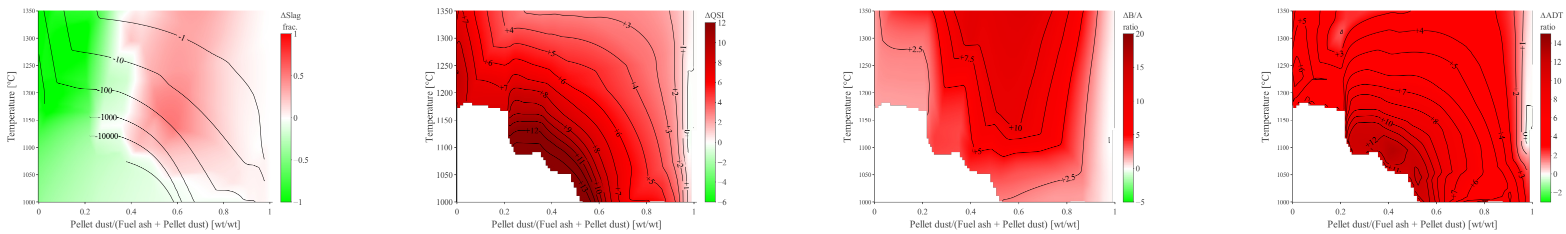
(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S36: Reed-Canary-grass difference (coal reference) plots



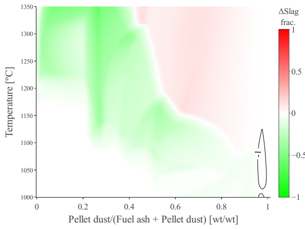
(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

Figure S37: Willow difference (coal reference) plots

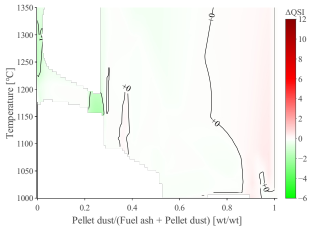


(a) Δ Slag frac. & visc. (b) Δ QSI (c) Δ B/A ratio (d) Δ ADT

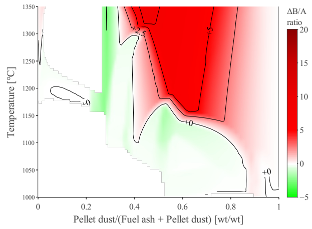
Figure S38: Stemwood difference (coal reference) plots



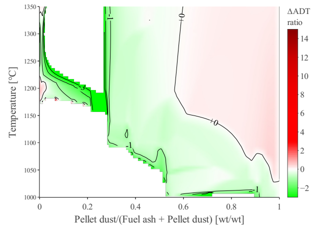
(a) Δ Slag frac. & visc.



(b) Δ QSI

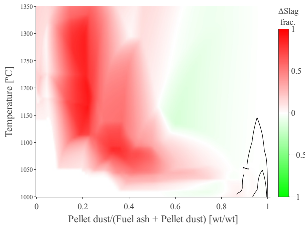


(c) Δ B/A ratio

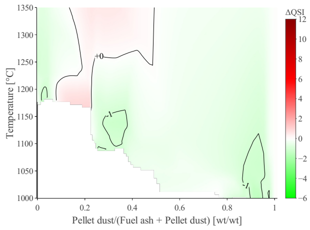


(d) Δ ADT

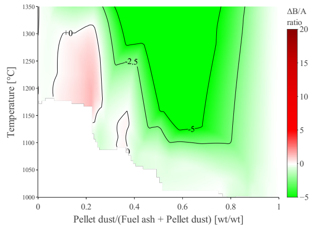
Figure S39: Bark difference (Biochar reference) plots



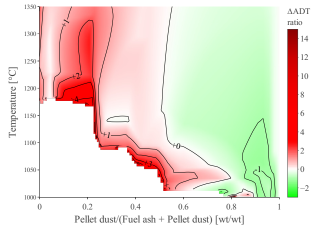
(a) Δ Slag frac. & visc.



(b) Δ QSI

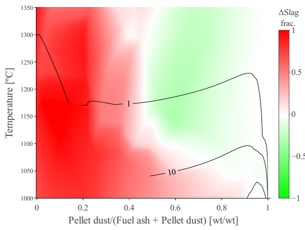


(c) Δ B/A ratio

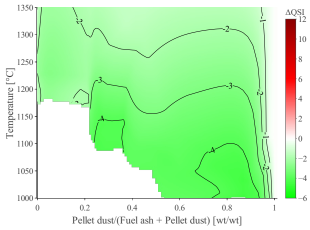


(d) Δ ADT

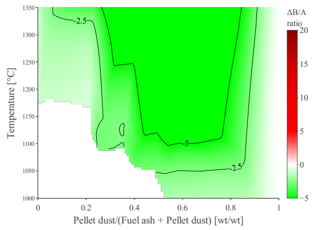
Figure S40: Forest residue difference (Biochar reference) plots



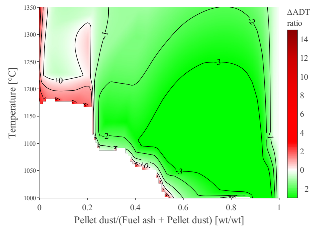
(a) Δ Slag frac. & visc.



(b) Δ QSI

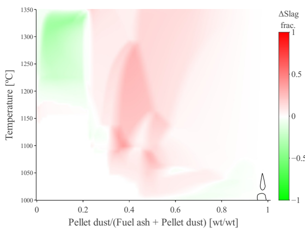


(c) Δ B/A ratio

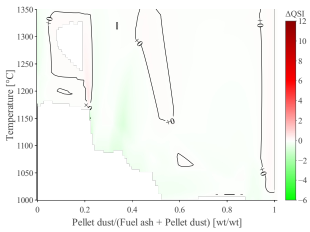


(d) Δ ADT

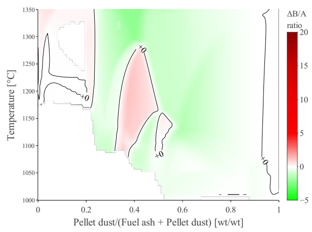
Figure S41: Reed-Canary-grass difference (Biochar reference) plots



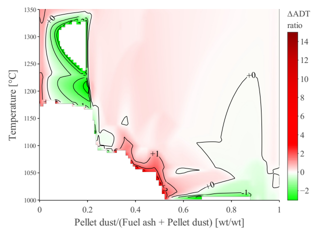
(a) Δ Slag frac. & visc.



(b) Δ QSI



(c) Δ B/A ratio



(d) Δ ADT

Figure S42: Willow difference (Biochar stemwood reference) plots

Section E_ Volatile behavior of ash

Description of the plot:

The total amount of vaporized ash (mg/MJ) for all the investigated fuels.

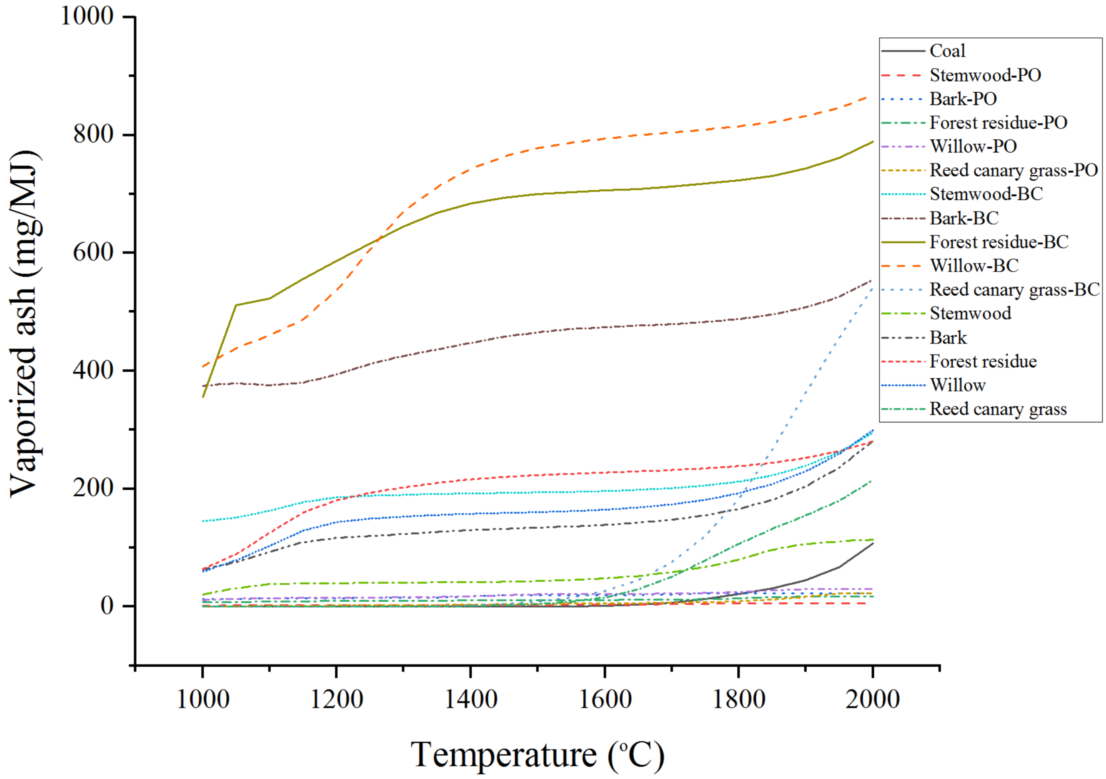


Figure S43: The total amount of vaporized ash (mg/MJ) for all the investigated fuels.