Research report no D3.1.4
Helsinki 2015

Tampere University of Technology
Maarit Särkilahti
Jaana Rajamäki
Thomas Kurka
Jukka Rintala

Plan for bioenergy and biomaterial loops in the future cities
Deliverable 3.1.4

Sustainable Bioenergy Solutions for Tomorrow

Cleen Oy
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ISBN 978-952-7205-21-1

Name of the report: Plan for bioenergy and biomaterial loops in the future cities

Key words: future city, city energy mix, biomass, bioenergy, CO2 emissions, modeling

Summary

Three bioenergy and biomass cases (Self-sufficient city, Regional bioeconomy and 5-15% CO_2 emission reduction) for Future City were developed. Moderate and progressive energy system development paths were studied. Future City Model (FCM) was developed and used to model Future City energy production mix, share of biomass used for energy production and energy production CO2 emissions. It was found that Future City's own biomasses i.e. waste streams counted to 1.392-1.814 MWh/capita/a. City's own biomass (Self-sufficient city) fulfilled bioenergy feedstock needs in 2020 and 2030, if energy system development follows moderate path, and almost fulfilled 2020 demand more progressive development, but in long term perspective (year 2030) progressive development required more biomass for bioenergy that Self-sufficient city could offer. When city's own biomass was used for energy production, 3.0-7.8% of Future City's total energy consumption could be covered. When all sustainably available forest and agro biomass from surrounding area was taken into account, bioenergy could cover up to 9.3-15.4% of total consumption.

Tampere, June 2015

Contents

1 Introduction

The future cities are expected to use energy efficiently from several sources with minimum emissions. Similarly different materials are expected to flow through the society, and be processed increasingly in biorefineries to variable valuable products besides bioenergy production.

The planning of future energy and material systems for cities may focus on new city areas, in which different energy sources and energy structures can be considered. Alternatively, planning can be considered for existing cities, assessing the potential future developments e.g. in population, energy consumption, energy technologies, and energy infrastructure.

Cities around the world have prepared plans and scenarios for their further development. Due to general concern over different environmental impacts, e.g. climate change, cities increasingly target to reduce greenhouse gas emissions and/or aim at carbon neutrality in their long term scenarios. Those city scenarios, as well as national targets, increasingly affect the development and implementation of energy systems in the cities.

The objective of this deliverable was to plan bioenergy and biomaterial loops for future cities, in this case for years 2020 and 2030. For that purpose an Excel based simplified Future City Model (FCM) was built. FCM can be used to model the Future City energy system and its greenhouse gas emissions with different uses of city biomasses.

The Future City Model was decided to be built on a forerunner city's energy scenarios (Deliverable 3.1.1), as these cities are most likely to adopt new energy technologies among the first ones. Two scenarios of Freiburg im Breisgau, representing mid-small German cities cluster (Deliverable 3.1.3), were used as data source for the FCM. The first scenario is based on a target of an environmentally neutral city with the decrease in CO_2 emissions by at least 90 % (scenario Ziel, Aim in English), and the other scenario is based on the current activities for environmental protection (scenario Referenz, Reference in English). (Kenkmann et al. 2011.)

The developed Future City Model was used to model three bioenergy and biomass cases for Future City : 1) Self-sufficient city using its own biomass, 2) Regional bioeconomy using city's own and regional biomass, and 3) 5-15% CO_2 emission reduction studying biomass needed for such a reductions. The objective of modeling was to assess the effects of different factors, such as biomass availability, and CO2 emission reduction targets, on the Future City energy system, e.g. on the bioenergy potential.

2 Materials and methods

This chapter presents methods used in estimating biomass availability in studied Future City bioenergy and biomass cases (Self-sufficient city, Regional bioeconomy and 5-15% CO_2 emission reduction), the Ziel and Referenz scenario data used in construction of the Future City Model (FCM), and principles of the FCM. Research frame is presented in the Figure 2.1.

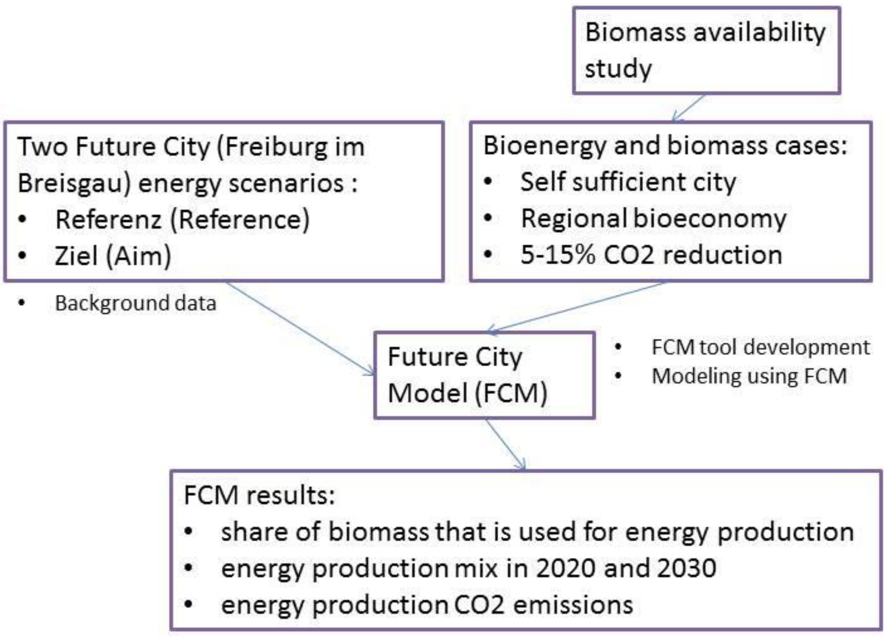

Figure 2.1 Biomass availability study was carried out in order to develop bioenergy and biomass cases (Self-sufficient city, Regional bioeconomy and 5-15% CO_2 emission reduction) for Future City. Future City energy system was adopted from two Freiburg city energy scenarios (Kenkmann et al. 2011). The scenarios (Referenz and Ziel) and bioenergy and biomass cases were used to develop Future City Model (FCM). FCM was used to model Future City energy production mix, share of biomass used for energy production and energy production CO2 emissions.

2.1 Future City biomass availability

This study (Task 3.1) focuses on urban biomass and bioenergy solutions where city's own biomass was assumed to be a prioritized feedstock for bioenergy production. Additional biomass was assumed to be available in the region surrounding the city.

In this study the city biomass was considered to include major municipal solid waste (MSW) fractions: biowaste, garden waste, paper and cardboard, and plastic, as well as municipal waste waters (MWW). Plastic, even though it is mostly produced from fossil materials, was included because it has high energy content, is often not reused, and is a significant waste stream in an urban context. The waste quantities and qualities of different waste fractions were from Biomaterial management in the future cities (Deliverable 3.1.2).

The amount of additional agricultural and forest biomass from surrounding region was calculated using sustainably available biomasses as described in the Atlas of EU biomass potentials (Elbersen et al. 2012). Agricultural biomasses included biofuel crops and energy maize, manure, straw, woody agricultural residues and grass from abandoned fields, and forest biomass included round wood, additionally harvestable round wood and primary forestry residues. The amount of biomass was calculated assuming equal amount of biomass per inhabitant and using the regional potential (Freiburg Regierungsbezirk, largest administrative division of a Land). The populations of the Freiburg city and the region are presented in Table 2.1.

Table 2.1: City and region populations used in Future City Model

Year	Freiburg region	Freiburg city
2011		229 144
2020	2216300	228392
2030	2205100	229506

2.2 Future City Model

2.2.1 Background data

A Future City Model (FCM) was constructed using MS Excel. The model uses two future energy system scenarios (Referenz and Ziel) for Future City (Freiburg im Breisgau). Referenz-scenario is based on the current activities for environmental protection, whereas Ziel-scenario is based on the idea of an environmentally neutral city with the decrease in CO_2 emission by at least 90 %. Scenario data used includes city energy production mix, energy consumption and population. (Kenkmann et al. 2011.) FCM focuses on near future urban energy systems, and the scenario data of years 2020 and 2030 is used. Both (Ziel and Referenz) scenarios energy production mix in 2020 and 2030 is presented in Table 2.2. In Ziel-scenario bioenergy production increases 75 % from 2020 to 2030, while increase in Referenz-scenario is only 13%. In Referenz-scenario, 58 % of city's energy is produced from natural gas in 2030, while in Ziel scenario 42 % of energy is produced from natural gas. **Table 2.2:** Energy production mix (GWh/a) by source in Referenz and Ziel scenarios. The energy production mixes is used and modified in Future City Model.

	Referenz 2020	Ziel 2020	Referenz 2030	Ziel 2030
Bioenergy (GWh/a)	113	344	128	603
Hydro energy	2	3	2	3
Wind energy	27	42	39	69
Solar energy	98	159	154	194
Landfill gas	1	1	1	1
Heat pumps	78	114	110	132
Natural gas	2440	2006	2136	1244
Coal	20	11	11	4
Heating oil	389	263	200	84
Petrol	307	271	251	184
Diesel	681	589	629	430
LPG	9	8	12	14
Hydrogen	0	3	1	9
Total	4166	3814	3674	2970

2.2.2 Assumptions

To meet with the requirements set for the modeling, the data given (Ziel and Referenz scenarios) was slightly modified, and some additional assumptions were made.

The CO_2 emissions from Future City energy production were calculated using standard fuel emission factors, which are based on the carbon content of each fuel, and CO2 emissions from biomass/biofuels are considered negligible. The present calculations as well as the standard emission factors ignore the emissions of the overall life cycle of the energy carrier. (Covenant of Mayors 2010.) The CO_2 emissions for imported electricity were calculated using the estimated national energy production mixes 2020 and 2030 (Schlesinger et al. 2014), and for the imported heat using the same heat production mix by fuel than in the heat production in the Freiburg city. However, all imported heat was assumed to be produced from heat alone processes separately, not by combined power and heat (CHP).

Applicable electricity-to-heat ratio and energy efficiency were assessed for FCM. Klobasa et al. (2011) investigated the potential of CHP energy production in Germany in CO_2 emission reduction with a focus in industrial applications, and stated that the average electricity-to-heat ratio in CHP installations in Germany is only 0.34, but that by modernization of the existing devices an electricity-to-fuel ratio over 0.7 can be achieved. As the modeling implemented in this deliverable is aiming to represent the future energy systems, the electricity-to-heat ratio was assumed to be somewhat higher than in the current situation. Furthermore, as the realization of the Ziel-scenario requires more advanced technical solutions than that of Referenz-scenario, the electricity-to-heat ratio of the Ziel-scenario was assumed to be slightly higher. Therefore, the electricity-to-heat ratio in CHP production was assumed to be 0.60 in the Referenz-scenario and 0.67 in the Ziel-scenario. The efficiency of the CHP energy production was assumed to be 80 % and the efficiency of separate heat production 30 %. The CHP heat production was assumed to be the maximum of CHP heat; all additional heat production was assumed to be produced separately. CHP production was also taken into account in estimating CO_2 emissions.

FCM was constructed to differentiate and to adjust the share of biomass that is used for bioproducts and the share used for bioenergy. In FCM, the decrease in bioenergy use is compensated by fossil energy production: if the share of bioproducts from biomass is increased, fossil energy production is increased and vice versa. Other renewable energy production is kept constant, as well as energy demand and its division in different segments (electricity, heat, and transport fuels).

3 Results

This study included biomass availability study, bioenergy and biomass case development, Future City Model development and modeling of Future City energy system focusing on a role of bioenergy. First the biomass availability was determined in order to develop bioenergy and biomass cases (Self-sufficient city, Regional bioeconomy and 5-15% CO_2 emission reduction) for Future City. Future City energy system was adopted from two Freiburg city energy scenarios (Kenkmann et al. 2011). The scenarios (Referenz and Ziel) and bioenergy and biomass cases were used to develop Future City Model (FCM). Subsequently FCM was used to model Future City energy production mix, share of biomass used for energy production and energy production CO2 emissions. Results of each step are presented next.

3.1 Biomass availability for Future City

The Future City (modified from Freiburg im Breisgau) biomass potential as well as agricultural and forest biomasses available in a region surrounding the city were estimated (Table 3.1) (Elbersen et al. 2012 and Deliverable 3.1.2). Altogether, waste streams count to 1.392-1.814 MWh/capita/a. Highest bioenergy potential is in forest surrounding the city (6.856 MWh/capita/a). Altogether agricultural biomass potential is 1.44 MWh/capita/a (2020) and 1.45 MWh/capita/a (2030). In near future agricultural residues have higher energy potential than agricultural crops, whereas in 2030 crops potential increases and residues potential decreases.

Table 3.1: Specific annual biomass energy potential (MWh/capita) for Future City in 2020 and 2030.

Biomass+waste energy potential (MWh/capita/a)	Freiburg 2020	Freiburg 2030
Forest biomass *	6.856	6.856
Agricultural crops	0.394	0.923
Agricultural residues	1.049	0.527
MSW bio+green*	0.113-0.263	0.113-0.263
MSW paper and cardboard*	0.511-0.535	0.511-0.535
MSW plastic*	0.498-0.746	0.498-0.746
MWW*	0.270	0.270

* current situation, assumed to stay similar

3.2 Bioenergy and biomaterial cases in Future City

Three bioenergy and biomaterial cases – Self-sufficient city, Regional bioeconomy and 5-15% CO_2 emission reduction – were developed. In each case, different share of biomass potential was used as a bioenergy feedstock. Future City energy mix was modeled according to bioenergy production in each case.

3.2.1 Self-sufficient city

In a bioenergy and biomaterial case Self-sufficient city, only city's own biomass was used for bioenergy production. Biomass flows are presented in Figure 3.1. Energy recovery should be the last step in the cascade of biomass usage, and therefore biomass was assumed to be only partly available for energy production.

Municipal waste water (MWW) energy potential was assumed to be used fully to energy production. Because 70% of MSW plastic is non-recyclable (Riber et al. 2009), it was assumed that 70% of the plastic fraction energy content is used for energy production and recyclable plastic, 30% of the fraction, is utilized as raw material to produce goods. Biodegradable fraction of MSW, bio, green, paper and cardboard, were assumed to be used as a feedstock of small biorefinery. According to Rättö et al. (2009) in biowaste based ethanol process, 50 % of dry matter is process waste and available e.g. to biogas process. The 50% assumption was used in this case. Depending on conversion technology selected, nutrients and other valuable compounds can be recovered at different stages of the process.

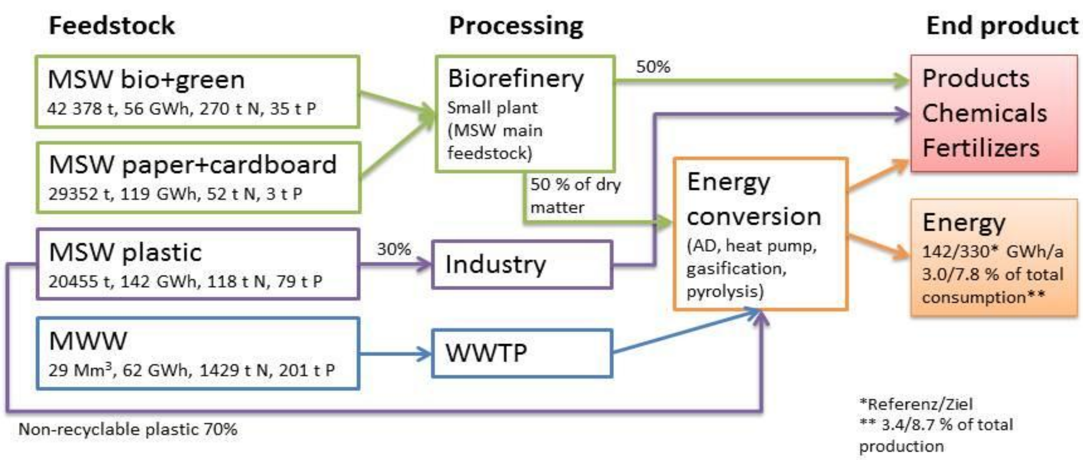

Figure 3.1: Biomaterial flows in a bioenergy and biomaterial case Self-sufficient city.

Future City energy mix (Referenz and Ziel scenarios) was modified according to Self-sufficient city biomaterial flows (Table 4.2). In this case biomass availability was restricted to city's own biomass that was used as described above (Figure 3.1). When compared to unmodified Referenz and Ziel scenarios (Table 2.2), Self-sufficient city case increased bioenergy in moderate Referenz scenario and decreased it in progressive Ziel scenario.

Table 3.2: Energy production (GWh/a) by source in Self-sufficient city case.

	Referenz 2020	Ziel 2020	Referenz 2030	Ziel 2030
Bioenergy	142	330	156	454
Hydro energy	2	3	2	3
Wind energy	27	42	39	69
Solar energy	98	159	154	194
Landfill gas	1	1	1	1
Heat pumps	78	114	110	132
Natural gas	2415	2018	2110	1384
Coal	20	11	11	4
Heating oil	386	265	198	93
Petrol	307	271	251	184
Diesel	681	589	629	430
LPG	9	8	12	14
Hydrogen	0	3	1	9
Total	4166	3814	3674	2970

3.2.2 Regional bioeconomy

In a bioenergy and biomaterial case Regional bioeconomy, city's own biomass was used for bioenergy production just like in the case Self-sufficient city. In addition forest and agricultural biomass from surrounding region was utilized to maximum extend that is sustainably available. All forest and agro biomass was assumed to go to a biorefinery, where 50% of dry matter is process waste and available for bioenergy production. Biorefinery is understood here widely and it includes industry that processes forest biomass to valuable products. Biomaterial flows in this case are presented in Figure 3.2.

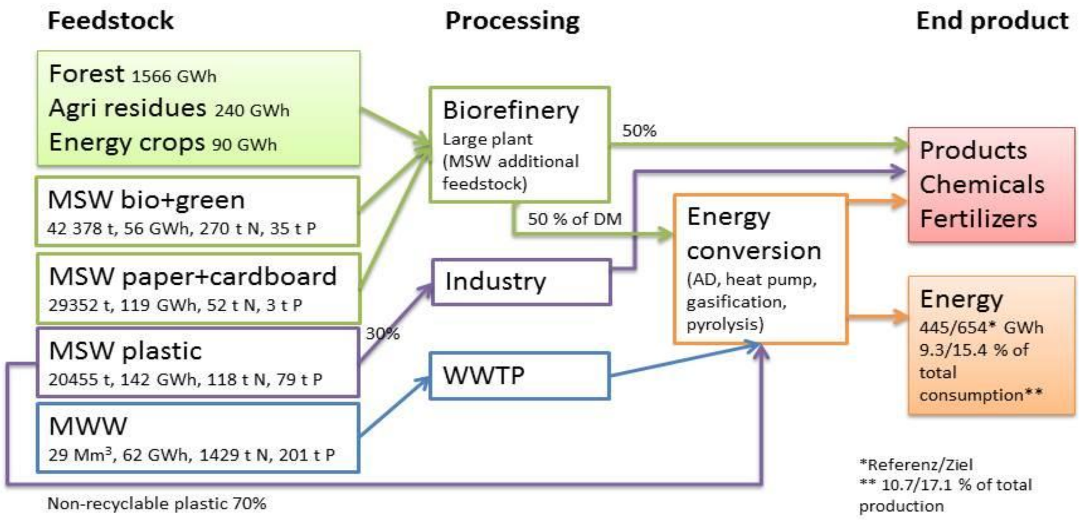

Figure 3.2: Biomaterial flows in a bioenergy and biomaterial case Regional bioeconomy.

Future City's energy mix in different scenarios that were modified according to Regional bioeconomy biomaterial flows is presented in Table 3.3. In this case biomass to bioenergy included city's own biomass as well as sustainably available forest and agro biomass from surrounding region (Figure 3.2). When compared to unmodified scenarios (Table 2.2), Regional bioeconomy case increased bioenergy in both, Referenz and Ziel scenarios.

Table 3.3: Energy production (GWh/a) by source in case Regional bioeconomy.

	Referenz 2020	Ziel 2020	Referenz 2030	Ziel 2030
Bioenergy	445	654	518	893
Hydro energy	2	3	2	3
Wind energy	27	42	39	69
Solar energy	98	159	154	194
Landfill gas	1	1	1	1
Heat pumps	78	114	110	132
Natural gas	2150	2018	1778	972
Coal	18	10	9	3
Heating oil	349	231	170	67
Petrol	307	271	251	184
Diesel	681	589	629	430
LPG	9	8	12	14
Hydrogen	0	3	1	9
Total	4166	3814	3674	2970

3.2.3 5-15% CO2 emission reduction

A bioenergy and biomaterial case 5-15% CO2 emission reduction was not based on selected biomasses but certain reduction in Future City's energy production CO2 emissions compared to unmodified Referenz and Ziel scenarios. Energy production mixes in this case are presented in Tables 3.4-3.6. Same information is presented graphically in Figures 3.3-3.5. When CO2 emissions were reduced by 15 % (Table 3.5), bioenergy production was close to that in the case Regional bioeconomy (Table 3.3). Even 5% reduction required more bioenergy than produced in the case Self-sufficient city (Table 3.2).

Table 3.4: Energy production (GWh/a) by source in a case 5 % CO_2 emission reduction.

	Referenz 2020	Ziel 2020	Referenz 2030	Ziel 2030
Bioenergy	291	494	278	697
Hydro energy	2	3	2	3
Wind energy	27	42	39	69
Solar energy	98	159	154	194
Landfill gas	1	1	1	1
Heat pumps	78	114	110	132
Natural gas	2285	1872	1998	1156
Coal	19	10	10	4
Heating oil	368	248	188	78
Petrol	307	271	251	184
Diesel	681	589	629	430
LPG	9	8	12	14
Hydrogen	0	3	1	9
Total	4166	3814	3674	2970

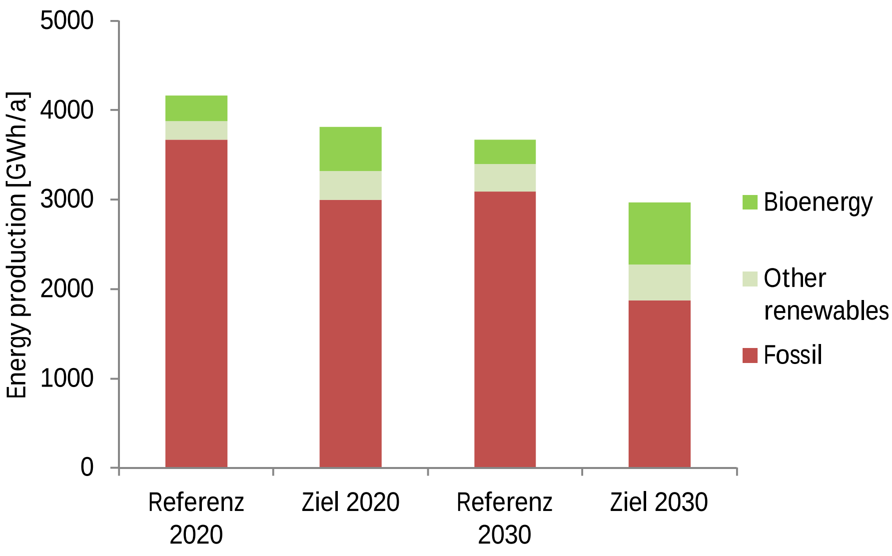

Figure 3.3: Energy production by source type in case of 5 % CO_2 emission reduction.

Table 3.5: Energy production (GWh/a) by source in case 10 % CO_2 emission reduction.

	Referenz 2020	Ziel 2020	Referenz 2030	Ziel 2030
Bioenergy	469	644	428	791
Hydro energy	2	3	2	3
Wind energy	27	42	39	69
Solar energy	98	159	154	194
Landfill gas	1	1	1	1
Heat pumps	78	114	110	132
Natural gas	2130	1738	1861	1067
Coal	18	10	10	3
Heating oil	346	232	177	73
Petrol	307	271	251	184
Diesel	681	589	629	430
LPG	9	8	12	14
Hydrogen	0	3	1	9
Total	4166	3814	3674	2970

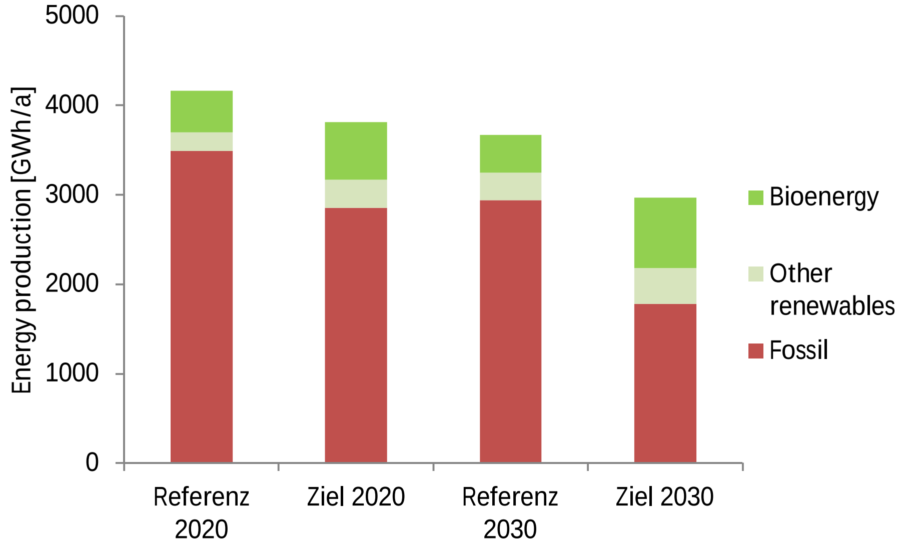

Figure 3.4: Energy production by source type in case 10 % CO_2 emission reduction.

Table 3.6: Energy production (GWh/a) by source in case 15 % CO_2 emission reduction.

	Referenz 2020	Ziel 2020	Referenz 2030	Ziel 2030
Bioenergy	647	794	577	885
Hydro energy	2	3	2	3
Wind energy	27	42	39	69
Solar energy	98	159	154	194
Landfill gas	1	1	1	1
Heat pumps	78	114	110	132
Natural gas	1975	1604	1723	979
Coal	17	9	9	3
Heating oil	325	217	165	67
Petrol	307	271	251	184
Diesel	681	589	629	430
LPG	9	8	12	14
Hydrogen	0	3	1	9
Total	4166	3814	3674	2970

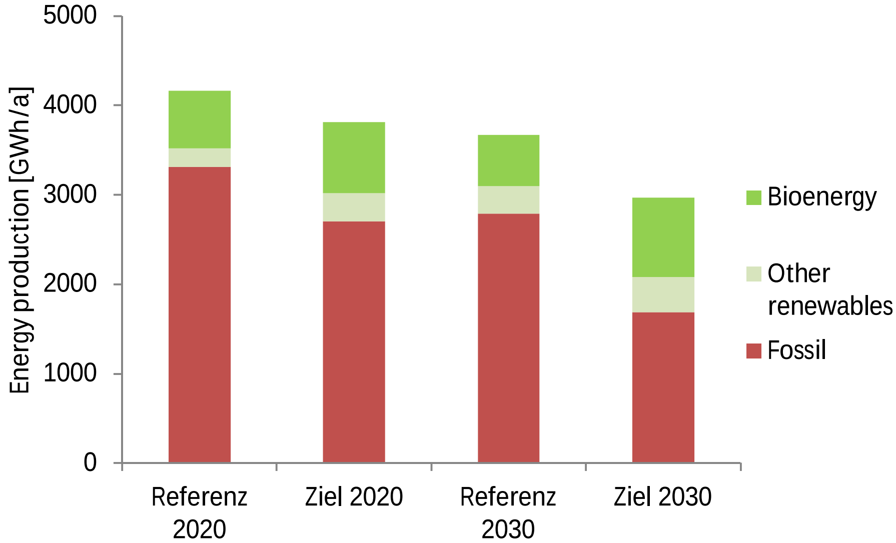

Figure 3.5: Energy production by source type in case 15 % CO_2 emission reduction.

3.3 Future City energy system modeling

Future City Modeling results included share of biomass that was used for energy production, energy production CO2 emissions and Future City energy production mix. Moderate (Referenz) and progressive (Ziel) energy system development paths were studied. Bioenergy and biomaterial cases enabled modifying those paths according to different choices in biomass use. Years 2020 and 2030 gave near future and long term perspectives to the development.

Firstly, biomass to bioenergy use (% of total biomass) and energy production CO2 emissions in Future City were modeled without changing biomass use according to bioenergy and biomaterial cases (Figure 3.6). Referenz scenario CO2 emissions in 2020 were similar to those of Ziel scenario in 2030.

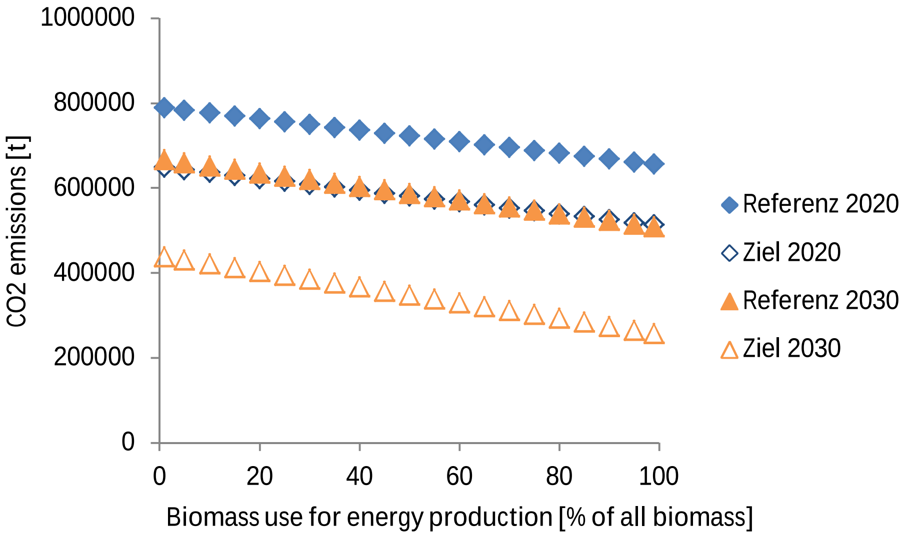

Figure 3.6: Future City (Referenz and Ziel scenarios) biomass to bioenergy use (% of total biomass) and energy production CO2 emissions from Future City Model.

3.3.1 Year 2020

Moderate development (Referenz)

Firstly, Future City biomass flows, role of bioenergy, energy production mix and CO2 emissions in 2020 were studied according to moderate energy system development path (Referenz scenario). Bioenergy and biomaterial cases were used to modify the path according to different choices in biomass use.

In Table 3.7 share of biomass that was used for energy production is presented together with Future City's energy production CO2 emissions. In Figure 3.7 same information is presented graphically. As seen in Figure 3.7, city's own biomass (Self-sufficient city) was enough to fulfill bioenergy feedstock demand. In Self-sufficient city, 10.7% of all biomass was used for bioenergy production. In Regional bioeconomy, 59.9% of all biomass was used for bioenergy and about 10% reduction in CO2 emissions compared to unmodified Referenz 2020 –scenario was achieved. 15 % CO2 emission reduction by increasing bioenergy was not possible within sustainable biomass resources available in the region.

Table 3.7: Share of biomass to bioenergy and energy production CO_2 emissions in different bioenergy and biomaterial cases based on Referenz 2020 –scenario.

	Share of bioenergy of all biomass [%]	CO_2 emissions [t]
Referenz 2020	6.0	781685
self-sufficient city	10.7	786855
support from surrounding area	59.9	709602
5 % CO_2 emission reduction	35.6	742601
10 % CO_2 emission reduction	58.4	703517
15 % CO_2 emission reduction	81.3	664433

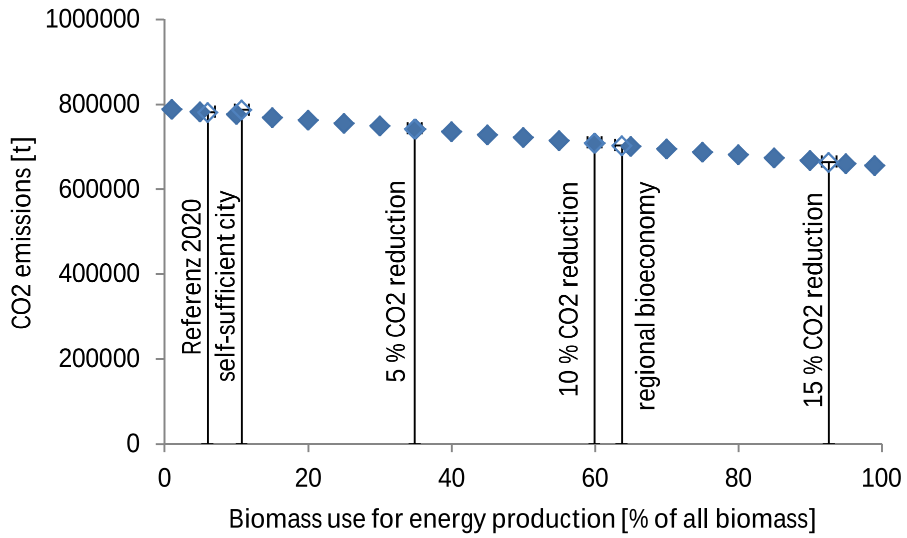

Figure 3.7: Energy production CO2 emissions as a function of the share of biomass used for energy production in different bioenergy and biomaterial cases based on Referenz 2020 –scenario.

In addition to previous data, energy mixes in different bioenergy and biomaterial cases based on Referenz 2020 –scenario, are presented in Figure 3.8.

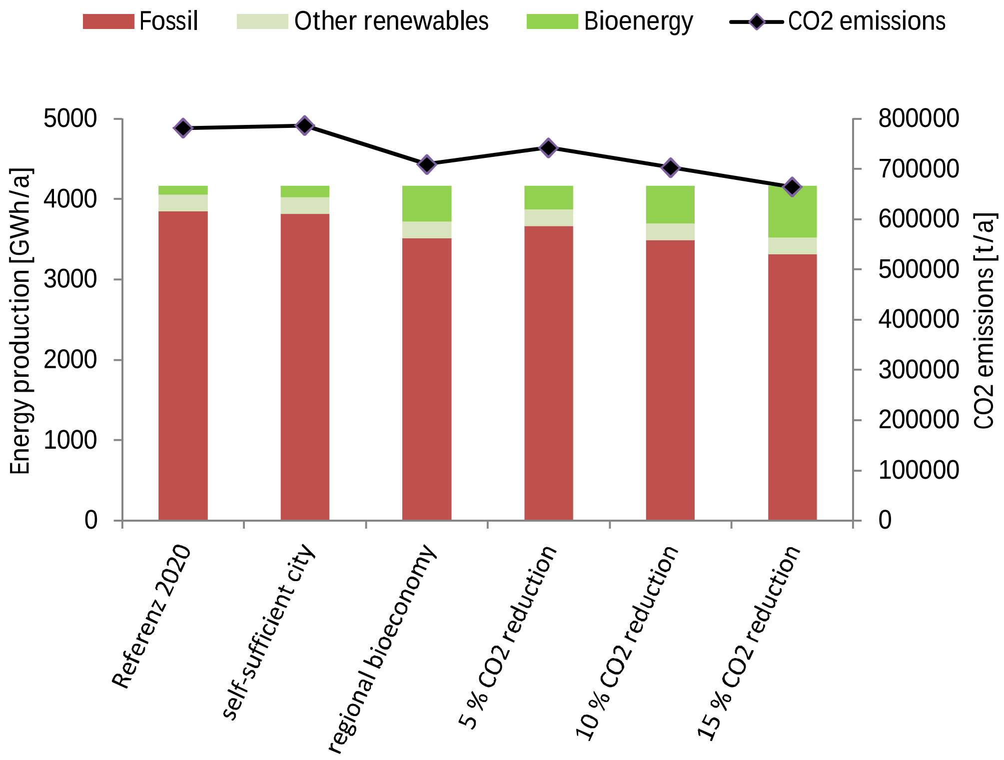

Figure 3.8: Energy production by source type and fuel CO2 emissions (bioenergy and biomaterial cases based on Referenz 2020 –scenario.).

Progressive development (Ziel)

Next, Future City biomass flows, role of bioenergy, energy production mix and CO2 emissions in 2020 were studied according to progressive energy system development path (Ziel scenario). Bioenergy and biomaterial cases were used to modify the path according to different choices in biomass use.

In Table 3.8 share of biomass that was used for energy production is presented together with Future City's energy production CO_2 emissions. In Figure 3.9 same information is presented graphically. As seen in Figure 3.9, city's own biomass (Self-sufficient city case) was not just enough to fulfill bioenergy feedstock demand. In Self-sufficient city 10.7% of all biomass was used for bioenergy production. Energy production CO_2 emissions based on Ziel 2020-scenario were 19% smaller than the emissions based on Referenz 2020-scenario. 15 % CO2 emission reduction from unmodified scenario by increasing bioenergy was not possible within sustainable biomass resources available in the region.

Table 3.8: Share of biomass to bioenergy and energy production CO_2 emissions in different bioenergy and biomaterial cases based on Ziel 2020 –scenario.

	Share of bioenergy of all biomass [%]	CO_2 emissions
Ziel 2020	12.8	632251
self-sufficient city	10.7	662333
support from surrounding area	59.9	568435
5 % CO_2 emission reduction	34.9	600639
10 % CO_2 emission reduction	63.7	569026
15 % CO_2 emission reduction	92.6	537414

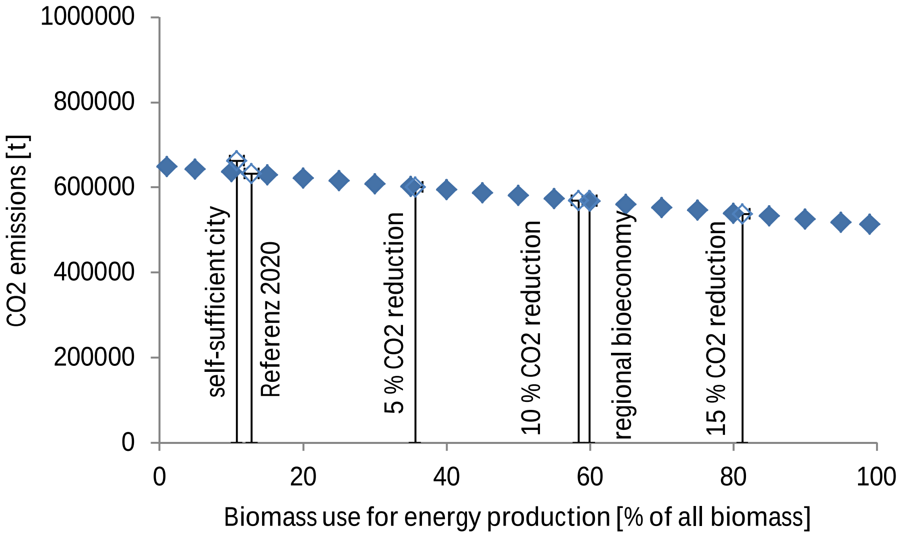

Figure 3.9: Energy production CO2 emissions as a function of the share of biomass used for energy production in different bioenergy and biomaterial cases based on Ziel 2020 –scenario.

In addition to previous data, energy mixes in different bioenergy and biomaterial cases based on Ziel 2020 –scenario, are presented in Figure 3.10.

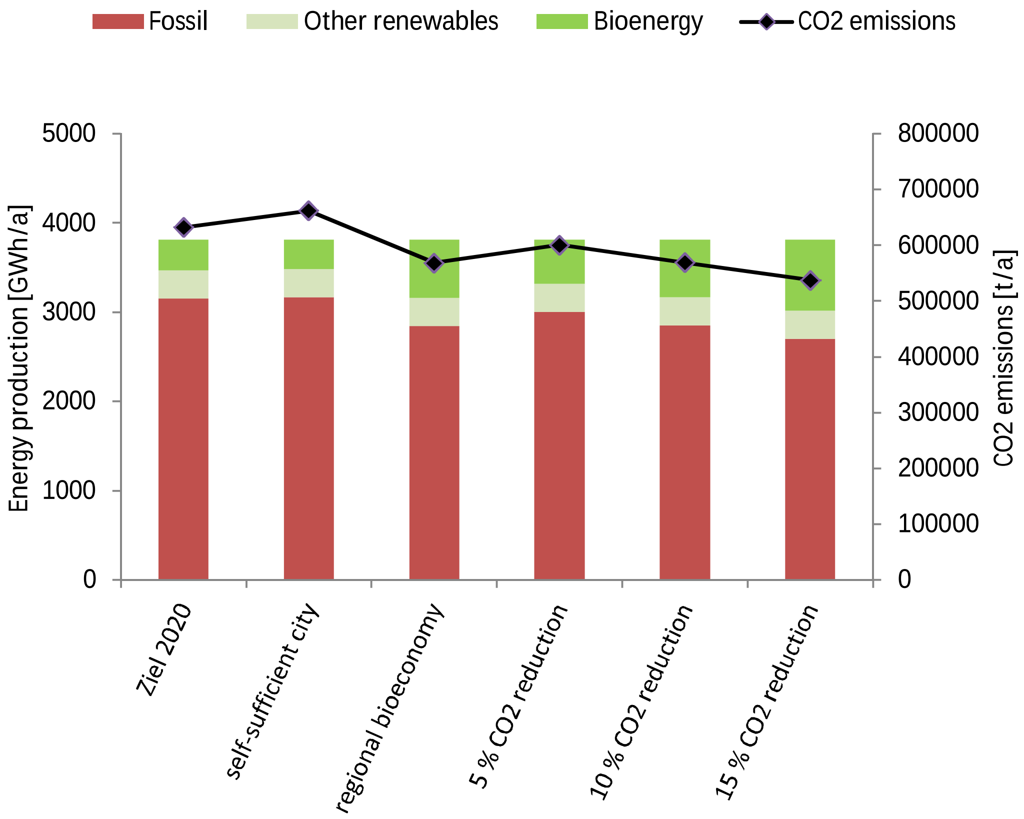

Figure 3.10: Energy production by source type and fuel CO2 emissions (bioenergy and biomaterial cases based on Ziel 2020 –scenario.).

3.3.2 Year 2030

Moderate development (Referenz)

Firstly, Future City biomass flows, role of bioenergy, energy production mix and CO2 emissions in 2030 were studied according to moderate energy system development path (Referenz scenario). Bioenergy and biomaterial cases were used to modify the path according to different choices in biomass use.

In Table 3.9 share of biomass that was used for energy production is presented together with Future City's energy production CO_2 emissions. In Figure 3.11 same information is presented graphically. By 2030 CO2 emissions of Referenz-scenario were almost as low as emissions of Ziel scenario in 2020 (Figure 3.9). As seen in the Figure 3.11, city's own biomass (Self-sufficient city) was enough to fulfill Referenz 2030 bioenergy feedstock demand and 12.8 % CO2 emission reduction was possible when all sustainably available biomass resources of the region (Regional bioeconomy) were used.

Table 3.9: Share of biomass to bioenergy and energy production CO_2 emissions in different bioenergy and biomaterial cases based on Referenz 2030 –scenario.

	Share of bioenergy of all biomass [%]	CO_2 emissions
Referenz 2030	6.9	656982
self-sufficient city	10.7	663182
support from surrounding area	59.9	572631
5 % CO_2 emission reduction	38.0	624133
10 % CO_2 emission reduction	48.6	591285
15 % CO_2 emission reduction	59.1	558435

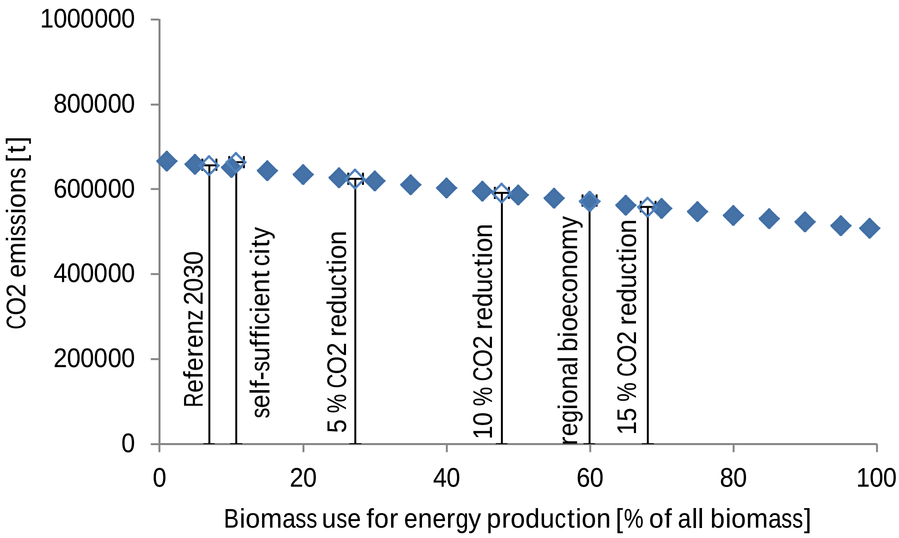

Figure 3.11: Energy production CO2 emissions as a function of the share of biomass used for energy production in different bioenergy and biomaterial cases based on Referenz 2030 –scenario.

In addition to previous data, energy mixes in different bioenergy and biomaterial cases based on Referenz 2030 –scenario, are presented in Figure 3.12.

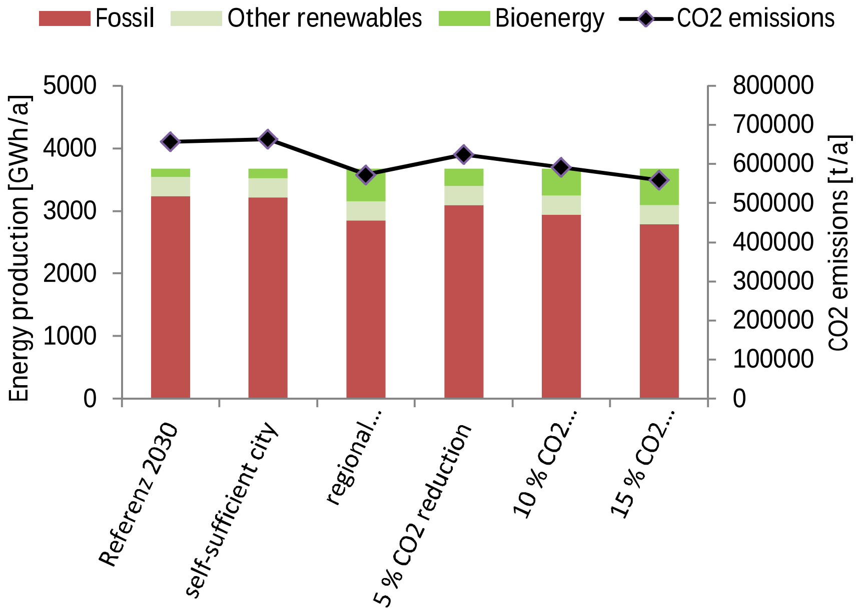

Figure 3.12: Energy production by source type and fuel CO2 emissions (bioenergy and biomaterial cases based on Referenz 2030 –scenario.).

Progressive development (Ziel)

Next, Future City biomass flows, role of bioenergy, energy production mix and CO2 emissions in 2030 were studied according to progressive energy system development path (Ziel scenario). Bioenergy and biomaterial cases were used to modify the path according to different choices in biomass use.

In Table 3.10 share of biomass that was used for energy production is presented together with Future City's energy production CO_2 emissions. In Figure 3.13 same information is presented graphically. In this case it is clearly seen that city's own biomass (Self-sufficient city) was not enough to fulfill bioenergy feedstock demand of unmodified Ziel 2030 scenario. In Regional bioeconomy, where all sustainably available biomass was used for bioenergy, about 13 % CO2 emission reduction compared to unmodified Ziel 2030 –scenario was achieved.

Table 3.10: Share of biomass to bioenergy and energy production CO_2 emissions in different bioenergy and biomaterial cases based on Ziel 2030 –scenario.

	Share of bioenergy of all biomass [%]	CO_2 emissions [t]
Ziel 2030	27.4	389856
self-sufficient city	10.7	456199
support from surrounding area	59.9	331849
5 % CO_2 emission reduction	27.3	370363
10 % CO_2 emission reduction	47.7	350871
15 % CO_2 emission reduction	68.1	331378

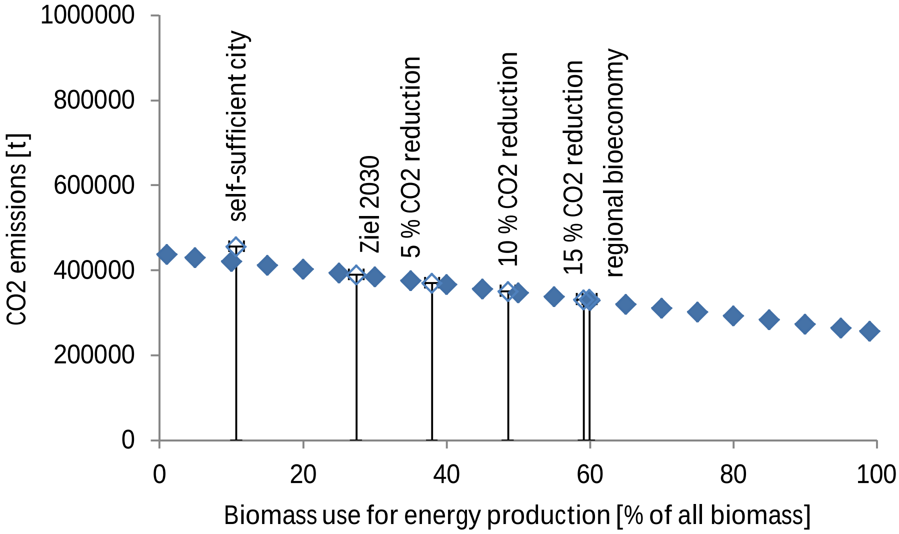

Figure 3.13: Energy production CO2 emissions as a function of the share of biomass used for energy production in different bioenergy and biomaterial cases based on Ziel 2030 –scenario.

In addition to previous data, energy mixes in different bioenergy and biomaterial cases based on Ziel 2030 –scenario, are presented in Figure 3.14.

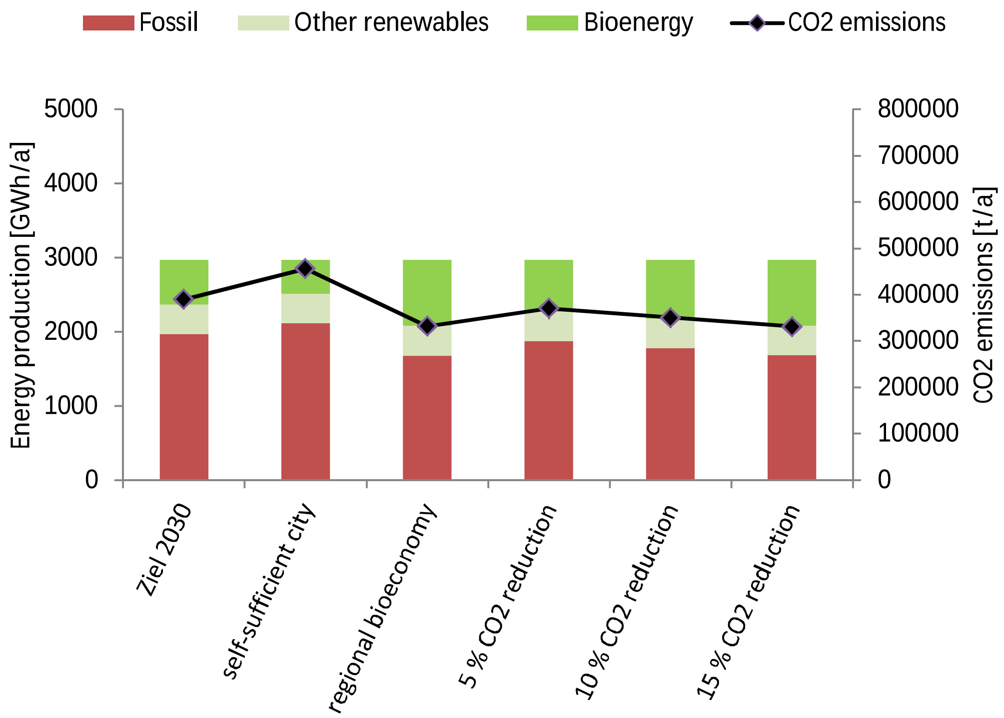

Figure 3.14: Energy production by source type and fuel CO2 emissions (bioenergy and biomaterial cases based on Referenz 2030)

4 Conclusions and discussion

Three bioenergy and biomass cases (Self-sufficient city, Regional bioeconomy and 5-15% CO2 emission reduction) for Future City were developed. Moderate (Referenz) and progressive (Ziel) energy system development paths were studied. Future City Model (FCM) was developed and used to model Future City energy production mix, share of biomass used for energy production and energy production CO2 emissions.

Key findings of the study:

- In terms of energy content, highest biomass potential was in forest (6.856 MWh/capita/a). Agricultural biomass potential was 1.44 MWh/capita/a (2020) and 1.45 MWh/capita/a (2030). Altogether, city's own biomasses i.e. waste streams counted to 1.392-1.814 MWh/capita/a.
- City's own biomass (Self-sufficient city) fulfilled bioenergy feedstock needs in 2020 and 2030, if energy system development follows moderate path (Referenz), and almost fulfilled 2020 demand more progressive development (Ziel). Whereas in long term perspective (2030)progressive development required more biomass for bioenergy that Self-sufficient city could offer. When all sustainably available biomass from surrounding area (Regional bioeconomy) was taken into account, higher bioenergy targets than those in Referenz and Ziel scenarios were possible.
- When city's own biomass was used for energy production, 3.0-7.8% of Future City's total energy consumption could be covered. When all sustainably available forest and agro biomass from surrounding area was taken into account, bioenergy could cover up to 9.3-15.4% of total consumption.
- Regional bioeconomy type biomass use enabled about 9.2-10.1% CO_2 emission reductions when compared to unmodified Referenz and Ziel 2020 scenarios. In 2030 12.8-14.9% reductions could be achieved. Self-sufficient city case decreased CO2 emissions little or not at all.

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Deliverable 3.1.2 Biomaterial management in the future cities (TUT). BEST project deliverable.

Deliverable 3.1.3 Report on role of bioenergy in the future cities (TUT). BEST project deliverable.

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