Sveučilište u Zagrebu

FACULTY OF MECHANICAL ENGINEERING AND NAVAL ARCHITECTURE

TOMISLAV PUKŠEC

INFLUENCE OF ENERGY POLICY ON LONG TERM ENERGY DEMAND PLANNING

DOCTORAL THESIS

Zagreb, 2015

Sveučilište u Zagrebu

FAKULTET STROJARSTVA I BRODOGRADNJE

TOMISLAV PUKŠEC

DUGOROČNO PLANIRANJE ENERGETSKE POTROŠNJE OVISNO O ENERGETSKOJ POLITICI

DOKTORSKI RAD

Zagreb, 2015

Sveučilište u Zagrebu

FACULTY OF MECHANICAL ENGINEERING AND NAVAL ARCHITECTURE

TOMISLAV PUKŠEC

INFLUENCE OF ENERGY POLICY ON LONG TERM ENERGY DEMAND PLANNING

DOCTORAL THESIS

SUPERVISOR:

Prof.dr.sc. NEVEN DUIĆ

Zagreb, 2015

Sveučilište u Zagrebu

FAKULTET STROJARSTVA I BRODOGRADNJE

TOMISLAV PUKŠEC

DUGOROČNO PLANIRANJE ENERGETSKE POTROŠNJE OVISNO O ENERGETSKOJ POLITICI

DOKTORSKI RAD

Mentor:

Prof.dr.sc. Neven Duić

Zagreb, 2015

BIBLIOGRAPHY DATA

UDC: 620.9:658.5

Keywords: energy demand planning, bottom up approach, energy policy, energy savings, scenario approach

Scientific area: TECHNICAL SCIENCES

Scientific field: Mechanical engineering

Institution: Faculty of Mechanical Engineering and Naval Architecture

Thesis supervisor: Prof.dr.sc. Neven Duić

Number of pages: 171

Number of figures: 74

Number of tables: 21

Number of references: 164

Date of examination:

Thesis defence commission:

Prof.dr.sc. Daniel Schneider – Chairman of defence commission

Prof.dr.sc. Neven Duić – PhD thesis supervisor

Prof.dr.sc. Igor Balen – member

Prof.dr.sc. Nataša Markovska – external member

Prof.dr.sc. Brian Vad Mathiesen – external member

Archive: Faculty of Mechanical Engineering and Naval Architecture

PREFACE

"As a single footstep will not make a path on the earth, so a single thought will not make a pathway in the mind. To make a deep physical path, we walk again and again. To make a deep mental path, we must think over and over the kind of thoughts we wish to dominate our lives."

Henry David Thoreau

ACKNOWLEDGEMENT

The work presented in this thesis is done mostly at the Department of Energy, Power Engineering and Environment of the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb. Part of the work was also carried out at the Aalborg University in Aalborg and Copenhagen, through the Croatian Science Foundation funding. First of all, I would like to thank my supervisor Prof. Neven Duić for all of his advices and guidance, which was essential in the making of this thesis. I would especially like to thank the members of the defence jury, professors Balen, Schneider, Markovska and Mathiesen for their inputs, comments and advices. Also, I would like to thank Dr. Helena Božić for all of her efforts, time and comments during the preliminary and final thesis defences. I would like to thank my colleagues Boris, Goran, Luka, Marko and Tomislav for all their inputs, advices, help and support in difficult times. I'm very grateful to Iva and Nevena, for all their help on the financial reporting for the EU projects. I would like to thank the Powerlab team for their friendship and support all these years. I would also like to thank all my friends and colleagues from the 8th floor, who created a good working atmosphere and made me feel welcomed. Special thanks go to colleagues and friends participating in the creation of the NeD model; Zlatko, Bojan, Dragomir, Tin and Tomislav. Finally, my greatest thanks go to my wife Dunja and son Andrija for being so supportive and patient with me. Also, I'm grateful to my family, my mother Tereza, father Andrija and sister Marina, who supported me all these years.

SUMMARY

Long term energy goals that the EU has set for the years 2020 and 2050, in order to increase its security of energy supply, decrease the impact on the environment and stimulate sustainability, are binding to all member states. Croatia as a new EU member state needs to reconsider and develop new energy policy towards energy efficiency and renewable energy sources. One of the key processes is rational energy consumption and gradual national energy demand decrease.

Having said this; it is important to understand what mechanisms are influencing energy demand and what is their long term impact, so future energy demand fluctuations can be modelled. Classical energy demand planning is usually focused on establishing a relationship between economic indicators, such as the GDP, and energy consumption. This is usually done based on analyzing different historical data and processing them in a relatively simple way, like time series analysis, or applying more complex analyses using neural networks, genetic algorithms or similar methods. It is argued that this approach has become inefficient in the case of EU countries which strive towards decoupling their economic growth and energy consumption. Numerous initiatives towards lowering energy consumption in the EU by implementing different Directives, financial schemes and mechanisms that should result in lowering energy demand in the future substantiate this argument.

A new approach in the energy demand planning process is necessary. In order to describe and quantify energy policy measures bottom up engineering models, focused on end users, have to be used. Throughout this thesis, the author has developed the National energy Demand model (NeD model) and used it to calculate long term final energy demand of Croatia. The model is based on sectoral approach and includes six major economic sub models; households, transport, industry, services, construction and agriculture. The results of the NeD model are compared to two available studies/models, the Primes EU28 and the Croatian national strategy. As an additional segment of this thesis is the implementation of the NeD methodology into LEAP model, in order to have more simplified long term energy demand model of Croatia which would be more easily used.

The main question that the author asks is: what is the effect of the implementation of various energy policies on the long term energy demand, primarily, but also what is the effect on the environment and national economy.

SAŽETAK

Dugoročni energetski ciljevi, koje je Europska komisija zadala za 2020. i 2050. godinu, u svrhu povećanja sigurnosti energetske opskrbe, smanjenja utjecaja na okoliš i poticanja održivosti, su obvezujući za sve zemlje članice. Hrvatska, kao nova zemlja članica mora preispitati i razviti novu energetsku politiku prema energetskoj učinkovitosti i obnovljivim izvorima energije. Jedan od ključnih elemenata je racionalna energetska potrošnja i njeno postupno smanjivanje.

Obzirom na izrečeno; izuzetno je bitno shvatiti koji su to mehanizmi koji utječu na energetsku potrošnju te koji je njihov dugoročni efekt. Klasični pristup energetskom planiranju potrošnje se fokusira na traženje međuovisnosti između makroekonomskih varijabli, kao što je bruto domaći proizvod, i potrošnje energije. To se obično radi analizom različitih setova povijesnih podataka koja može biti vrlo jednostavna, kao vremenski nizovi, ili relativno kompleksna, kao što su genetski algoritmi, neuronske mreže ili neke slične metode.

Ovakav pristup je postao nedovoljan, pogotovo u slučaju zemalja EU, koje čine sve kako bi razdvojile svoj gospodarski rast i potrošnju energije. Brojne inicijative, usmjerene ka smanjenju potrošnje energije unutar EU, primjenom različitih direktiva, financijskih mehanizama za posljedicu će imati smanjenje potrošnje energije uz planirani gospodarski rast.

Novi pristup kod planiranja energetske potrošnje je potreban. Kako bi se opisali i kvantificirali mehanizmi energetske politike, energetski modeli koji počivaju na pristupu odozdo prema gore fokusirani na krajnjeg korisnika, trebaju biti primijenjeni. Kroz ovu tezu autor je razvio National energy Demand model (NeD model), te ga iskoristio kako bi izračunao dugoročnu finalnu potrošnju Republike Hrvatske. Model je baziran na sektorskom pristupu te uključuje šest glavnih ekonomskih sektora: kućanstva, transport, industrija, usluge, poljoprivreda, te građevinarstvo. Rezultati NeD modela su uspoređeni s dva modela/studije, Primes EU28 te nacionalnom energetskom strategijom. Kao dodatna komponenta ove teze jest implementacija NeD metoda i postupaka u LEAP model, kako bi imali jednostavan za koristiti dugoročni model energetske potrošnje Republike Hrvatske.

Glavno pitanje koje si autor teze postavlja je: kakav će biti efekt implementacije mjera energetske politike na dugoročnu energetsku potrošnju, ali i okoliš.

PROŠIRENI SAŽETAK

Ključne riječi: planiranje energetske potrošnje, pristup odozdo prema gore, energetska politika,energetske uštede, scenarijski pristup

Glavni cilj Europske komisije je smanjenje emisija stakleničkih plinova u Uniji za 80-95% do 2050. u usporedbi s 1990. Kvalitetno planiranje buduće energetske potrošnje, u svrhu ostvarivanja navedenog cilja, postaje važno. Teza daje alternativu klasičnom pristupu planiranja potrošnje energije, temeljenom na metodi elasticiteta koja promatra međuovisnost energetske potrošnje i bruto domaćeg proizvoda. Obzirom da se metoda temelji na analizi historijskih indikatora, ona ne može kvalitetno predvidjeti utjecaj energetske politike te razvoja tehnologije. Primjenom naprednih odozdo prema gore (*engl. bottom up*) tehno-ekonomskih metoda koje uzimaju u obzir fizikalnu pozadinu procesa korištenja i pretvorbe energije, moguće je identificirati značajne buduće energetske uštede, smanjenje utjecaja na okoliš te smanjenje energetske ovisnosti o uvoznim energentima. Rezultati istraživanja, kroz razvoj i aplikaciju vlastitih modela, pokazuju da je striktnom primjenom mjera energetske politike do 2050., u Republici Hrvatskoj moguće smanjiti emisije CO_2 za 50% u odnosu na današnju razinu.

Planiranjem energetske potrošnje postavljamo temelje razvitka svakog energetskog sustava, bilo da se radi o manjoj cjelini ili cijeloj državi. Nakon što je dana procjena budućih potreba za energijom možemo krenuti u kvalitetno planiranje opskrbe, odnosno u analizu samog energetskog sustava. Na taj način možemo odrediti kako bi sustav optimalno trebao izgledati, a da pritom bude u stanju zadovoljiti projicirane energetske potrebe. Pri planiranju energetske potrošnje kao imperativ se nameće uključivanje zakonodavnih i financijskih mehanizama, razvoja tehnologije, porezne politike i sl. Planiranje energetske potrošnje ostvarujemo kombiniranjem raznih parametara, kao što su energetske bilance, energetske politike, specifične potrošnje, specifični vremenski periodi. te njihovom međusobnom interakcijom. Prvi korak u tom procesu je odabir ili izrada vlastite metode koja opisuje probleme, izazove, ulazne podatke, matematičke relacije te pruža konačno rješenje. Kada se govori o pristupu podatcima i načinu izrade metoda i postupaka u literaturi se koriste dva načelna pristupa: odozdo prema gore (*engl. bottom up*) te odozgo prema dolje pristup (*engl. top down*). Tipični pristup odozdo prema gore (*bottom up*) promatra zasebne tehnologije te energetske bilance i

knjigovodstvo za pojedinog potrošača te njihovim sumiranjem dolazi do željenih rezultata (Subhes et al.). Ovaj pristup se fokusira na energetskom sustavu kao takvom, a ne na njegovoj interakciji s ekonomijom kao cjelinom. Tipični pristup odozgo prema dolje (*top down*) promatra ekonomiju kao cjelinu i rezultate fokusira prema povijesno kalibriranim rezultatima te prati vezu između energetske potrošnje i BDP-a. Fokus je na mehanizmima i procesima koji su na tržištu, a ne toliko na samoj tehnologiji. Kod ovog pristupa postoji više različitih pod-pristupa kao što su kompjuterski modeli ravnoteže, ekonometrijski modeli, ali i više hibridnih modela koji kombiniraju i tehnologijske podatke s ekonomskim procesima (Barker et al.). Činjenica je da je često teško naći razliku između dva navedena pristupa te se neki modeli iz literature lako mogu svrstati i pod jedan i pod drugi pristup. IPCC AR4 izvještaj koristi top down terminologiju za sve modele koji imaju integracijski pristup dok bottom up terminologiju koristi za sve modele koji se fokusiraju na individualnu tehnologiju. Iz literature proizlazi da bottom up modeli obično predviđaju nižu potrebu za energijom (low demand), uz kvalitetniji opis mjera energetske učinkovitosti, za razliku od top down modela. Upravo tu dolazi do takozvanog rascjepa u energetskoj učinkovitosti (*engl. energy efficiency gap*) (Koopmans). Rascjep se često objašnjava kombinacijom bottom up informacija s nerealnim diskontnim stopama. Druga razina modeliranja metodom odozdo prema gore odnosi se na izlaz (*engl. phase out*) odnosno ulaz (*engl. phase in*) određenih tehnologija koje se ne mogu modelirati faktorima porasta energetske učinkovitosti. Primjer zgradarstva i transportnog sektora možemo uzeti kao ogledni primjer, gdje s ulazom dizalica topline te električnih vozila imamo skok energetske učinkovitosti s faktorom 5. U literaturi se koristi kombinacija navedenih pristupa koji najčešće imaju top down pristup, ali isto tako koriste bottom up informacije kako bi odredili neke od parametara (Wiesmann et al.). Druga vrlo česta kategorizacija, prisutna u literaturi, temeljena na različitim filozofijama u određivanju dugoročne energetske potrošnje poznaje tri pristupa; ekonometrijski modeli, modeli fokusirani na krajnjeg korisnika (*engl. end-use*) te hibridni modeli (Subhes et al.).

Ekonometrijski pristup predstavlja kvantitativnu metodu koja uspostavlja međuovisnost između zavisne i nezavisne varijable statističkom analizom povijesnih podataka dok modeli fokusirani na krajnjeg korisnika promatraju potrošnju energije na neagregiranoj razini. Predložena teza odnosi se na bottom up end-use dugoročne modele za planiranje energetske potrošnje, koji u obzir uzimaju i tehnologije koje su u fazi istraživanja i razvoja, a koje mogu imati veliku ulogu kod određivanja buduće potrošnje. Oni projiciraju potrošnju na razini krajnjih korisnika te se na temelju procijenjenih normi potrošnje energije, za određenu aktivnost u budućnosti i poznavanju kvantitete aktivnosti, može odrediti buduća potrošnja energije (Richardson i Liu). Ovakvi modeli izrazito su pogodni za dugoročne procjene potrošnje energije, no traže vrlo visoku razinu potrebnih podataka glede kvantitete i kvalitete (Widen et al.). Pregledom literature susreću se modeli pojedinih ekonomskih sektora koji onda mogu biti i ukomponirani u cjeloviti model za planiranje energetske potrošnje na nacionalnoj razini (Huang et al. i Amirnekooei et al.). Pritom treba imati na umu da svaki ekonomski sektor nosi svoje specifičnosti koje u inženjerskom bottom up modelu treba opisati i kvantificirati. U literaturi, nacionalnu sektorsku podjelu možemo opisati s tri glavna sektora; zgradarstvo, industrija i transport (Subhes et al.). Prvi korak u razvoju bottom up inženjerskog modela predstavlja modeliranje bazne godine, temeljem koje je moguće izvršiti kalibraciju te verifikaciju svih ulaznih parametara. Autori u (Subhes et al.) predstavljaju formalizirani koncept modeliranja bazne godine. U radu (Pukšec et al.) autori su pokazali kako stroga primjena energetske politike (npr. dio regulative koji se odnosi na novogradnju i obnovu starogradnje) dugoročno utječe na smanjenje finalne potrošnje u sektoru kućanstva. Da bi se svaka od predloženih mjera kvantificirala autori su napravili detaljan bottom up model koji polazi od modeliranja korisnih površina samog sektora. Primjenom termodinamičkih postavki dobivaju detaljnu geografsku distribuciju rashladnog i toplinskog učinka na razini korisne energije.

U radu (Irsag et al.) autori su razvili sličan bottom up model za predviđanje dugoročne potrošnje sektora turizma s razlikom u pristupu modeliranja vanjske ovojnice sektora te pojednostavljenom termodinamičkom izračunu. Osnovni razlog tome jest veliko ograničenje pristupu ulaznim podatcima koji su presudni za funkcioniranje modela. Koliko je tehnološki razvoj te energetska politika važna prilikom modeliranja sektora zgradarstva pokazali su autori u (Broin i Guivera). Rezultati pokazuju da prethodno spomenuta dva parametra mogu biti značajnija od ponašanja i životnog stila samih korisnika, kada se analizira potrošnja energije. Autori su pokazali kako se ukupna finalna potrošnja u EU, u 2050. godini, može smanjiti za 50%, u usporedbi s 2005. godinom, ukoliko se ostvari rast energetske učinkovitosti veći od 2% godišnje. Isto tako su pokazali da se EU ciljevi po pitanju emisija CO_2 mogu ostvariti samo ukoliko se oslonimo na električnu energiju i područno grijanje koji dolaze iz nisko ugljičnih tehnologija.

Analizom prometnog sektora u (Pukšec et al.) autori su pokazali kako se značajne uštede u finalnoj potrošnji kao i emisijama CO_2 mogu očekivati kroz tri glavna mehanizma; povećanje energetske učinkovitosti motora s unutarnjim izgaranjem (u korelaciji s EU direktivama), elektrifikaciju segmenta transporta u kojem je to tehnički izvedivo, prije svega segment osobnih vozila, te postupnog intermodalnog prijelaza s energetski intenzivnih oblika prijevoza robe i putnika na manje intenzivne. Razvijeni bottom up model fokusiran je na dinamiku populacije određenog tipa vozila koja uključuje životni vijek, kao i ulaz, odnosno izlaz pojedine vrste vozila. Dinamika populacije vozila temeljena je na novim propisima te očekivanom razvoju tehnologija. U segmentu osobnih vozila najznačajniji je ulaz hibridnih te električnih vozila, kao i postepena implementacija biogoriva. U sektoru transporta zanimljivo je analizirati odnose cijena energenata na potrošnju samih derivata. Autori u (Solis et al.) pokazali su da umjerena povećanja cijena derivata neće donijeti smanjenje potrošnje energije već je to jedino moguće strogom energetskom politikom koja se odnosi na povećanje učinkovitosti. Za potrebe svoje analize autori su izradili jednostavan bottom up model kojim su ujedno analizirali mogućnosti smanjenja emisija CO_2 putem intermodalnog prijelaza s energetski intenzivnih oblika prijevoza na one manje intenzivne.

U industrijskom sektoru autori su u (Bačelić et al.) identificirali četiri glavna parametra koja su presudna u procjenama energetske potrošnje kod bottom up modela. Uvozno/izvozna komponenta određuje udio domaće industrijske proizvodnje što je u direktnoj vezi s potrošnjom energije. Drugi parametar je moguće nastajanje ili nestajanje određenog tipa industrije. Razvoj tehnologije te energetska učinkovitost izuzetno su bitne u industrijskom sektoru te će u budućnosti igrati važnu ulogu. Kao konačan parametar bitan za predviđanje energetske potrošnje industrijskog sektora jest miks goriva koji uključuje različite opcije zamjene pojedinih goriva novim. Većina bottom up modela koja se bave procjenom dugoročne potrošnje sektora industrije fokusiraju se na tehnologiju te energetsku učinkovitost. U radu (Seck et al.) autori su se fokusirali na rekuperaciju topline te analizirali njen učinak na dugoročnu potrošnju u francuskoj prehrambenoj industriji. U istom radu je razmatrano pitanje korištenja top down i bottom up pristupa pri modeliranju sektora industrije, odnosno jednog od njenih podsektora. Obzirom na već prethodno spomenutu argumentaciju, autori dolaze do zaključka da je korištenje bottom up pristupa u sektoru industrije jedina opcija, ukoliko se želi kvantificirati utjecaj energetske učinkovitosti i novih tehnologija na buduću energetsku potrošnju. U konačnici autori se odlučuju za komercijalan TIMES model kako bi analizirali utjecaj i mogućnosti rekuperacije topline u francuskoj prehrambenoj industriji. Kroz analizu literature vidljiv je izraziti sektorski pristup, kad je riječ o detaljnim i naprednim inženjerskim bottom up modelima, sa nedostatkom cjelovitog modela koji je u stanju modelirati energetsku potrošnju na nacionalnoj razini. Jedan od razloga za to je svakako izuzetna razina detaljnosti individualnih sektorskih modela što u konačnici nacionalne modele čini pre kompleksnima. Komercijalni bottom up modeli su uglavnom pojednostavljeni kako bi sa što jednostavnijim setom podataka, usmjerenim na makroekonomske parametre, dali dugoročne procjene energetske potrošnje na nacionalnoj razini.

CILJ I HIPOTEZA

Cilj teze je razvoj napredne metode i matematičkog modela za modeliranje neposredne potrošnje energije uz implementaciju energetske regulative. Metoda je bazirana i testirana kroz sektorsku analizu na nacionalnoj razini te se kroz analizu pokazalo na koji način i pod kojim uvjetima je moguća implementacija mehanizama energetske politike u svrhu ostvarivanja maksimalnih ušteda energije te smanjenja utjecaja na okoliš. Rad je provjerio i potvrdio hipotezu da je naprednim energetskim planiranjem temeljenim na inženjerskom bottom up pristupu, uzimajući u obzir sve aspekte energetske politike, moguće identificirati mjere koje će u RH do 2050. godine dovesti do značajnih ušteda energije i smanjenja finalne potrošnje, smanjenog utjecaja na okoliš te smanjene ovisnosti o uvoznim energentima na nacionalnoj razini.

OČEKIVANI ZNANSTVENI DOPRINOS

Ideja je bila pronaći novu metodu koja će kombinacijom više pristupa koji se koriste pri energetskom planiranju pronaći novi i kvalitetniji matematički model planiranja energetske potrošnje. Ovaj novi model uzima u obzir sve glavne tehnološke aspekte, ali i pravne te financijske mehanizme koji isto tako utječu na potrošnju energije. Na ovaj je način stvoren vlastiti model testiran i provjeren na primjeru Republike Hrvatske, ali isto tako primjenjiv i na druge sustave globalno.

METODE I POSTUPCI

Izrada vlastitog modela za dugoročno planiranje potrošnje, koji će biti sposoban analizirati energetske sustave na nacionalnoj razini, temelji se na nekoliko koraka. U prvom koraku fokus je na izradi zasebnih modela koji će analizirati i davati procjenu dugoročne potrošnje na sektorskoj razini. Šest osnovnih ekonomskih sektora je odabrano; industrija, transport, kućanstva, usluge, poljoprivreda i građevinarstvo. Ovakva podjela odabrana je temeljem nacionalne energetske bilance u Hrvatskoj, obzirom da će razvijeni model biti testiran upravo na primjeru Republike Hrvatske. U literaturi se javljaju i druge kombinacije u kojima se sektor poljoprivrede često svrstava pod industriju te sektor građevinarstva pod promet. Odabrana podjela otvara mogućnost kvalitetnije validacije rezultata modela te kasnije usporedbe rezultata s eventualno novim analizama i studijama. Za razradu sektora kućanstva koristit će se HED model (Pukšec et al.). Isti model koristit će se i za uslužni sektor s iznimkom pod-sektora ugostiteljstva i turizma koji će biti temeljen na (Irsag et al.). Glavne mjere uključivati će implementaciju EPBD-a (*engl. Energy Performance of Buildings Directive*) kroz strogo reguliranu gradnju novih te rekonstrukciju postojećih zgrada. Model uzima 2020. godinu kao ključnu u široj implementaciji skoro pa energetski neutralnih zgrada, dok se do te godine model oslanja na postojeći zakonski okvir koji vrijedi u RH vezan za racionalnu uporabu energije u zgradama. Zgrade u RH troše oko 40% finalne energije pa njihova renovacija predstavlja veliki potencijal. Renovacija zgrade u određenoj godini u budućnosti podrazumijeva iste propise i standarde koji u istoj godini vrijede i za novogradnju. Model će analizom osjetljivosti od 1% do 3% pokazati kako godišnja stopa obnove zgrada utječe na ukupnu finalnu potrošnju, što je u skladu s direktivom o energetskoj učinkovitosti (*engl. Energy Efficiency Directive*).

Kod implementacije transportnog sektora u nacionalni model koristit će se EDT model opisan u radu (Pukšec et al.). Model implementira EU regulativu koja se odnosi na energetsku učinkovitost motora s unutarnjim izgaranjem (g CO_2/km) te na taj način regulira populacije vozila različitih energetskih učinkovitosti, odnosno energetske potrošnje. Kalkulacija je postavljena tako da nova vozila koja ulaze u sustav dostignu 130 g CO_2/km u 2015. godini, dok je za 2021. godinu ta granica postavljena na 95 g CO_2/km. Jedna od potencijalnih mjera biti će analiza transportnog sustava s potpunom elektrifikacijom segmenta osobnih vozila u 2050. godini te potpunim izlazom LPG-a (ukapljeni naftni plin, *engl. Liquefied Petroleum*

Gas) u 2030. godini. Važno će biti ispitati rezultat implementacije direktive koja se odnosi na promicanje uporabe energije iz obnovljivih izvora energije (*engl. Renewable Energy Sources Directive*), s posebnim osvrtom na potencijal ulaska biogoriva u transportnom sektoru. Navedena Direktiva predviđa udio od 10% obnovljivih izvora energije u transportnom sektoru u 2020. godini.

Za razradu sektora industrije koristi će se IED model (Bačelić et al.) dok će se za preostala dva sektora, poljoprivredu i građevinarstvo, pristupit izradi novih modela koji će biti implementirani u nacionalni model. Kao zadnja velika cjelina nacionalnog modela, slijedi implementacija modula koji će biti zadužen za računanje emisija stakleničkih plinova (GHG modul). Spomenuti modul obuhvatiti će sve prethodno spomenute sektorske modele te će na temelju njihovih rezultata računati emisije stakleničkih plinova na nacionalnoj razini. Izračun emisija stakleničkih plinova temeljiti će se na IPCC (*engl. Intergovernmental Panel on Climate Change*) metodi koja će biti implementirana u model kao ulazni podatak. Izradi svih sektorskih modela prethodi sakupljanje, validacija i jednostavno testiranje ulaznih podataka, prvenstveno energetskih bilanci te raznih statističkih podataka. Nakon toga slijedi izrada samog matematičkog modela koji se temelji na određenoj baznoj godini. Razrada modela na baznoj godini se radi obzirom da su tada poznati i ulazni i izlazni podatci pa je moguće na taj način verificirati sam model ili pak izračunati pojedine parametre koji u baznoj godini nisu dostupni. Slijedi analiza energetske regulative (*engl. energy policy implementation*). Prije same implementacije energetske regulative te financijskih mehanizama potrebno je izraditi referentni scenarij koji se poslužiti kao svojevrsna usporedba (e*ngl. benchmarking*) za kasniju analizu i modeliranje. Modeliranje tehnološkog razvoja unutar modela temeljeno je na implementaciji raznih tehnologija u baznoj godini te njihovom daljnjom modifikacijom u samom procesu modeliranja dugoročne potrošnje.

Izrada modela biti će rađena u Excel alatu Microsoft Office paketa. Na taj način postiže se šira kompatibilnost prvenstveno pri obradi i implementaciji podataka koji su dobiveni u prethodnim fazama rada. Isto tako otvara se mogućnost jednostavnih nadogradnji modela te prilagodbi za eventualno druge nacionalne energetske sustave. Rezultat rada jest gotov paket, odnosno model, koji je sposoban napraviti scenarije i analizu finalne potrošnje energije za bilo koji energetski sustav, uključujući i pod-sektorizaciju. Kao zadnji korak u izradi rada slijedi testiranje razvijenog modela na primjeru Republike Hrvatske te njenog energetskog sustava. Prilikom testiranja vlastitog modela pokazano će biti kako određena mjera energetske politike dugoročno utječe na energetsku potrošnju, odnosno kakav je utjecaj određene tehnološke mjere na istu. Kako bi se odradila usporedba rezultata dobivenih vlastitim modelima, autor će koristiti komercijalni model za planiranje energetske potrošnje LEAP (*engl. Long range Energy Alternatives Planning System*). Usporedba rezultata biti će moguća samo u sklopu ograničenja koja posjeduje LEAP model.

KEY WORDS

energy demand planning, bottom up approach, energy policy, energy savings, scenario approach

KLJUČNE RIJEČI

planiranje energetske potrošnje, pristup odozdo prema gore, energetska politika,energetske uštede, scenarijski pristup

NOMENCLATURE

Symbol	Description	Unit
A_i	total available floor area in a certain county	m^2
P_i	population of a certain county	
M_i	specific available floor area of a certain county	m^2/person
z	year for which the calculation is made	
N_i	new available floor area in a certain county	m^2
D_i	demolished floor area in a certain county	m^2
R_i	renovated available floor area in a certain county	m^2
S	renovation paste index	
tR_i	total renovated building stock	m^2
tN_i	total new building stock	m^2
Bs_i	“old” building stock	m^2
Q_i	total heat demand	PJ
Qt_i	heat transfer due to transmission	PJ
Qv_i	heat transfer due to ventilation	PJ
Qs_i	solar heat gains	PJ
Qi_i	internal heat gains	PJ
h	share of floor area heated	%
v	wall percentage of available envelope surface	%
w	window percentage of available envelope surface	%
vU_i	thermal transmittance of walls	kW/m^2K
wU_i	thermal transmittance of windows	kW/m^2K

Ae_i	available envelope surface	m^2
ΔT_i	temperature difference between outside monthly average temperature and inside temperature	K
t	duration of calculation step	h
he	average height of heated floor area	m
n_{ex}	air exchange rate	s^{-1}
ρ	air density	kg/m^3
cp	air heat capacity	J/kgK
q^z	airflow	m^3/h
Aw_i	effecting collecting area	m^2
g	solar energy transmittance of transparent element	
af_i	frame reduction factor	
ps_i	shading reduction factor	
I_i	solar irradiance	W/m^2
c	share of floor area cooled	
Qc_i	total cooling demand	PJ
Dd_i	cooling degree days	
E_i	final energy consumption of a certain electric appliances category	PJ
sp_i	specific consumption of a certain electric appliances category	kWh/m^2
l_i	energy efficiency improvements index in a certain year	
Ea_i	final energy consumption for space cooling	PJ
COP_i	coefficient of performance index	
F_i	final energy demand	PJ
fd_i	energy demand	PJ

ee_i	energy efficiency index	
r_i	share ratio of a certain fuel type index	
trD_i	energy demand of a certain category of road transport	PJ
trE_i	number of vehicles of a certain category of road transport	
trM_i	fuel consumption of vehicles of a certain category of road transport	l/100 km
Cv_i	fuel consumption energy efficiency index	
P_i	usage of vehicles of a certain road transport category	km/year
Cm_i	usage efficiency index	
trQ_i	heating value of a fuel type that a vehicle is using	MJ/l
z	year for which the calculation is made	
trN_i	vehicles entering the system	
Cf_i	vehicles exiting the system	
$N_i c$	conventional personal vehicles entering the system	
n_i	total number of personal vehicles entering the system	
Cn	share of a certain type of conventional personal vehicles in the total number of personal vehicles entering the system every year	
$N_i a$	alternative personal vehicles entering the system	
K_i	newly registered alternative vehicles	
trR	energy demand of rail transport	PJ
e_i	energy consumption of a certain fuel type	PJ
m_i	number of a certain vehicle type	
a_i	average yearly consumption of a certain vehicle type	t/year
b_i	energy efficiency index of a certain vehicle type	
trq_i	heating value of fuel used by a certain vehicle	MJ/kg

m_id	number of diesel vehicles in the system	
mn_i	number of diesel vehicles exiting the system	
m_ie	number of electrical vehicles in the system	
mm_i	new electrical vehicles entering the system	
cs	technology switch index	
Air	energy demand of air transport	PJ
k_i	kilometres flown	km
cn_i	yearly fuel consumption	kg/km
qk_i	heating value of fuel	MJ/kg
trl_i	yearly kilometres flown of a certain aircraft type	km
p_i	number of aircrafts	
Sea	energy demand of sea and river transport subsector	PJ
Sr	energy consumption of river transport	PJ
Ss	energy consumption of costal sea transport	PJ
riv	river transport fuel consumption	t/year
trp	available power	kW
pp	specific consumption	t/kW
Cp	river transport fuel consumption energy efficiency index	
s	costal transport fuel consumption	t/year
B	number of vessels	
bb	specific consumption of a vessel	t/year
Cj	coastal transport fuel consumption energy efficiency index	
U_i	consumption of a certain type of fuel,	tonne, kWh
u_i	consumption of a certain type of vehicle	tonne, kWh

fe	energy efficiency index of a certain vehicle type	
t_i	number of vehicles	
$Q_{P,C}$	quantity of each product per capita in reference year	t/capita
$Q_{P,D}$	total production quantity of each product for domestic market	t
Q_I	total import quantity of each product	t
N_{CAP}	total population	
$Q_{P,Cx}$	specific product consumption per capita in each year	t/capita
i_x	defined change in consumption per capita	%
$\mathrm{Q}_{\mathrm{i,x}}$	quantity of each group of products for domestic market in each year	t
$\mathrm{i}_{\mathrm{I,x}}$	import share for specific industry	%
$Q_{P,Ix}$	import quantity of each group of products	t
$\mathrm{Q}_{\mathrm{EXP,x}}$	export quantity of a product in the observed year	t
$\mathrm{Q}_{\mathrm{EXP,x-1}}$	export quantity of a product in the previous year	t
$i_{EXP,x}$	change in export quantities for the observed year in comparison to the previous year	%
$E_{SP,ind}$	specific energy consumption of industry	MJ/t
E_{ind}	total final energy consumption of each industry	PJ
P_{DOM}	total amount of products produced within the industry, including both product quantities for domestic market and product quantities for export	t
$A_{i\ spec}^{z}$	specific available surface of a certain category of a subsector in a specific year (e.g. hospitals, schools)	m^2/capita
B_i^z	available floor area of a certain category of a subsector in a specific year (e.g. hospitals, schools)	m^2
P^z	population in a specific year	
EI_a	energy intensity of the agricultural production of a certain crop	MJ/t
E_a	energy intensity of the agricultural production of a certain crop	MJ/ha
P_a	crop productivity	t/ha

EC_a	energy consumption of the agricultural production of a certain crop	MJ/year
CP_a	crop production	t/year
EC_{ah}	energy consumption of animal husbandry for a certain animal	MJ/year
EI_{ah}	energy intensity of animal husbandry for a certain kind of animal	MJ/animal
NOE	number of animals	animal/year
F_{ij}^{z}	yearly energy demand of a different fuel type for a certain energy consumption category	PJ
$L_{ij\ spec}^{z}$	specific energy consumption of a different fuel type for a certain energy consumption category	PJ/m^2, PJ/construction site
C_j^{z}	yearly property of a certain energy consumption category	m^2, number of construction sites
G_i^{z}	yearly amount of CO_2 emitted from a certain fuel type	tCO_2
S_i^{z}	specific CO_2 emission conversion factor of a certain fuel	tCO_2/GJ
K_i^{z}	yearly amount of various fuel consumed	GJ
B_{tou}	number of beds	
HU_{tou}	number of housing units	
SQF	floor surface	m^2
B_{Q2}	basic square footage for two bed rooms	m^2
AF	added factor	
B_{Q3}	basic square footage for three bed rooms	m^2
H	number of hotels	
P_{SA}	percentage of studio apartments	%
P_R	percentage of rooms	%
P_A	percentage of apartments	%

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Background

In the light of the European energy-climate package and its measures for increasing security of supply, decreasing the impact on the environment and stimulating sustainability, Croatia, as a new EU member state, needs to reconsider and develop new energy policy towards energy efficiency and renewable energy sources.

In order to achieve these goals in a defined time frame, a new approach in the energy planning process is necessary, together with clear and realistic energy strategies. Demand/Supply interaction requires a new holistic approach, balancing optimal energy system with realistic energy demand, taking into consideration most significant parameters. On the demand side planning, identification of key drivers and mechanisms influencing energy demand is necessary, as well as their quantification. This includes from both legal and financial to purely technological mechanisms. An integral energy strategy has a final goal of achieving national energy independence and long term economic growth based on new „green jobs“.

Security of supply and energy independence represents a strategic interest of any country [1]. Croatia's own current energy supply is 50% with negative expecting trends, falling to 21-23% till 2030 [2]. As a result of this, the national economy is at the risk of various price shocks and market distortions. Turning to renewable energy sources and various energy efficiency measures, based on national production capacities, present the key to higher energy independence [3].

Croatia has experienced a steady growth of final energy demand until 1990 with a peak of 275.67 PJ in 1987 [4]. Industry consumed 38% of the final energy at that time, transport 20% and other sectors combined for the remaining 42% [4]. Following the collapse of the Socialist Federal Republic of Yugoslavia and the ensuing war, Croatia's industry was devastated and the overall energy consumption, especially in the industry sector, experienced a substantial decline. The transport and other sectors began to recover and the energy demand started to increase again. The total final energy consumption reached the pre-war levels by 2010 [4]. The industrial sector, however, never recovered. The energy consumption of Croatia's industry remained at the post-war level until 2008 when it experienced another drop caused by the European wide recession. The final energy consumption of the industry, transport and other sectors in Croatia from 1985 until 2011 is shown in Figure 1. Households, services, agriculture and construction are included under other sectors.

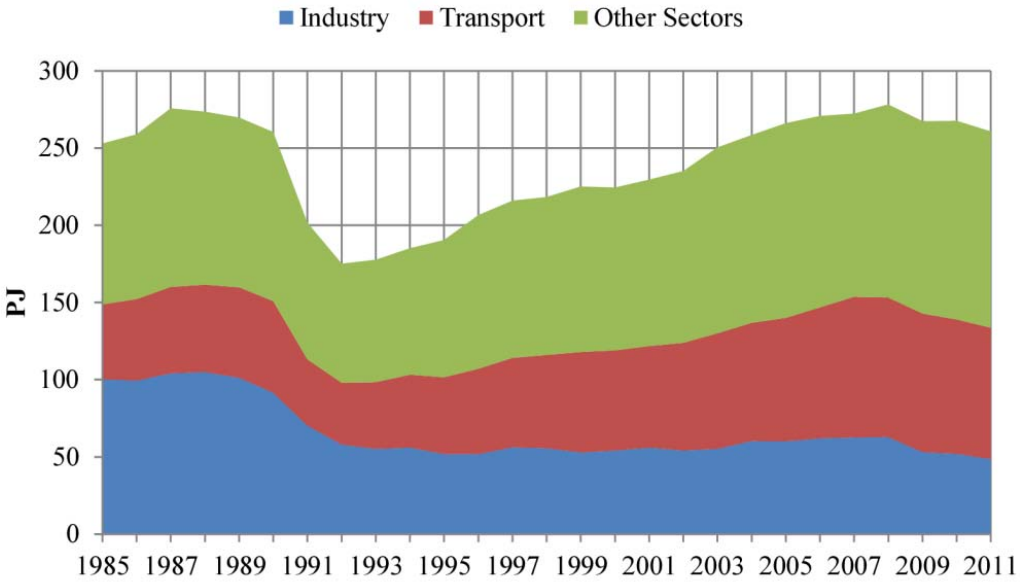


Figure 1 Final energy consumption by sectors in Croatia [4]

Energy strategy should be observed as a starting point in the strategic development of the industry and creating new green jobs. Creating new industrial niches in the domain of low carbon technologies should be observed as an opportunity for the Republic of Croatia. The transition to a low carbon society will mean driving in electric or hybrid cars [5], living in very efficient or energy neutral buildings [6] and generally living in a cleaner environment [7][8]. In order to achieve this, renewable energy sources, smart grids and cities, more efficient technologies will be necessary [9][10]. The financial price of this transition is assessed to around 270 billion euros on the EU level, or around 1,5% of the total GDP in the next 40 years. This investment cycle will result in creating new types of industry since holding and creating new high tech jobs is an absolute priority for the EU. The European Commission expects the creation of 1,5 million new jobs till 2020, as a result of the European energy and climate pack [11]. Energy sector, households and services sectors are expected to decrease their energy consumption by 30% till 2050 in comparison to 2005. At the same time they will enjoy the benefits of more quality services, as a consequence of technological development.

Distributed energy sources, as a complementary mean to energy efficiency improvements, present a big opportunity from both energy and financial point of view. On average, the EU has the opportunity to save from 175 – 325 billion euros on fuel costs in the next forty years [11].

Modelling long term energy demand is the first step towards advanced energy system analysis since its results present one of the key input data used for energy system optimization [12][13]. In order to plan sustainable and energy efficient energy system, precise energy demand projection is crucial [14][15]. With this approach, the system can be optimized in order to satisfy all demand side needs.

Classical energy demand planning is usually focused on establishing a relationship between economic indicators, such as the GDP, and energy consumption [16][17]. This is usually done based on analysing different historical data and processing them in a relatively simple way, like time series analysis, or applying more complex analyses using neural networks, genetic algorithms or similar methods [18][19]. It is argued that this approach has become inefficient in the case of EU countries which strive towards decoupling their economic growth and energy consumption. Numerous initiatives towards lowering energy consumption in the EU by implementing different Directives, financial schemes and mechanisms that should result in lowering energy demand in the future substantiate this argument [20][21]. If the primary energy consumption and the GDP growth are compared, it is visible that in Croatia's case these two factors are still linked. The increase in GDP is followed by the increase in energy demand until the late 2000s when the country experienced a crisis, lowering the GDP, and as a result the energy consumption has decreased as well [22]. GDP and the primary energy consumption for Croatia for the period from 1992 until 2010 are presented in Figure 2.

Decoupling economic growth and energy consumption is possible. Implementing various energy policy measures could lead to significant decrease of energy consumption and GHG emission in Croatia until 2050. The same data as shown in Figure 2 for Croatia is shown in Figure 3 for Denmark.

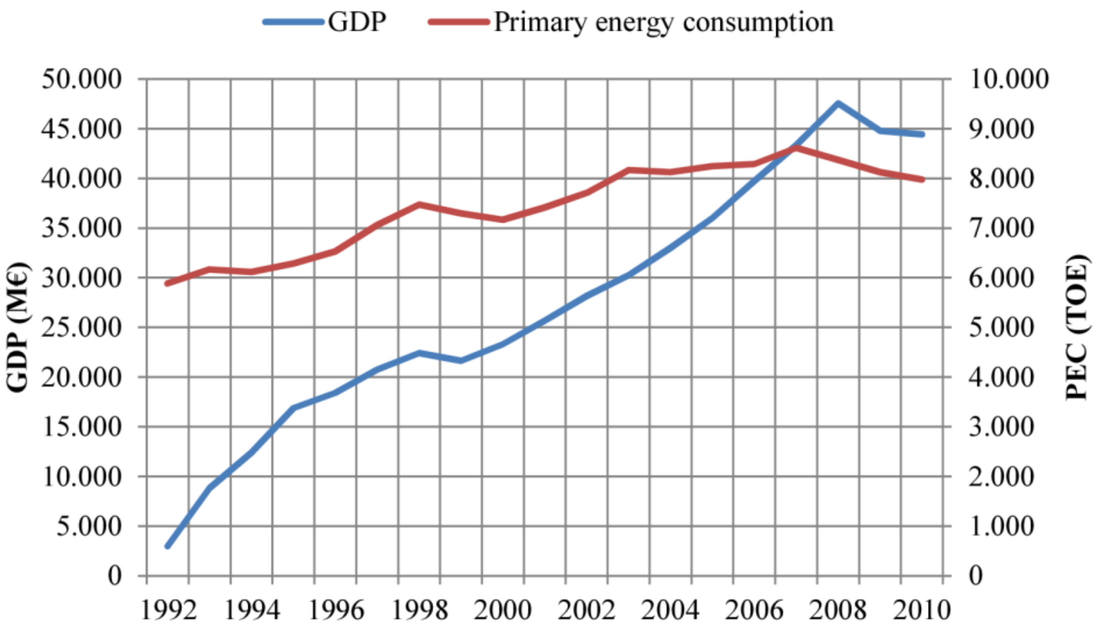


Figure 2 GDP growth and primary energy consumption in Croatia [22]

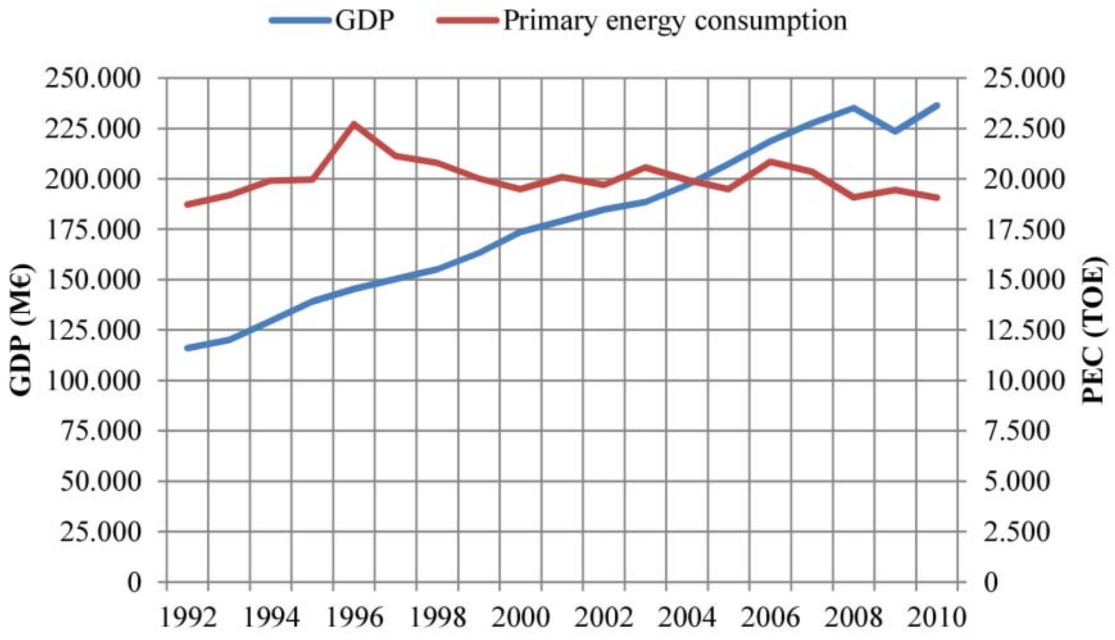


Figure 3 GDP growth and primary energy consumption in Denmark [22]

Evidently, Denmark has successfully decoupled their increase in GDP and energy consumption. This means that Denmark has increased its overall energy efficiency while Croatia still has to achieve the same (goal).

Croatian final energy intensity is presented for the period from 1995 until 2010 in Figure 4. Generally declining trend could be noticed, which would mean a gradual increase of energy efficiency.

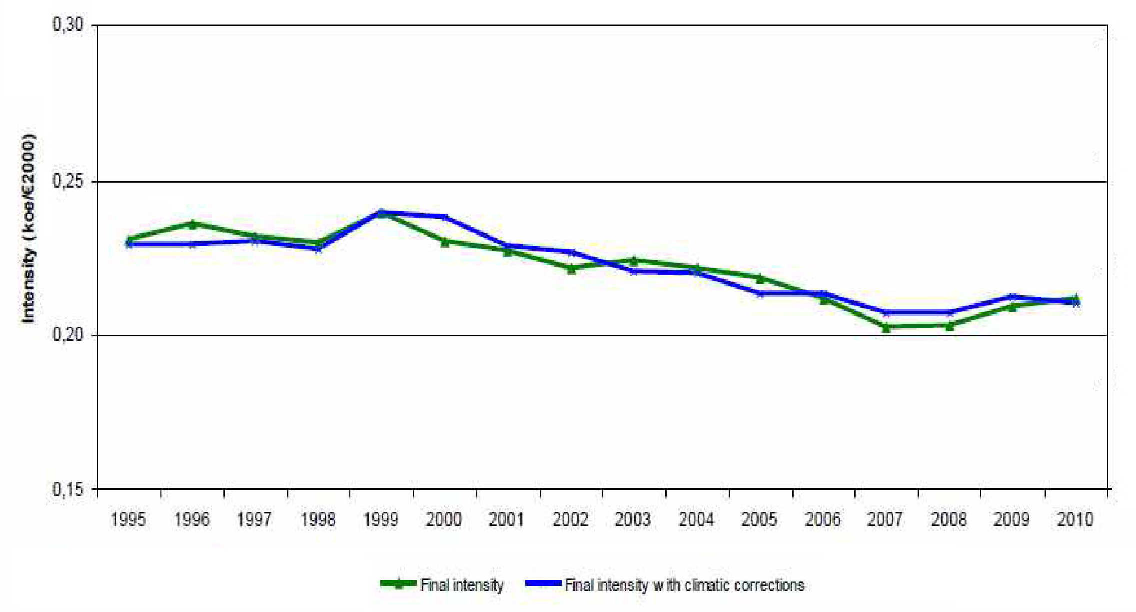


Figure 4 Croatian final energy intensity until 2010[1]

Sustainable development based on realistic and rational energy planning is the prerequisite for ecological development, which today is a first rate question. Green house gas emissions, their control and quantification are becoming one of the key issues in the energy planning process.

Latest research shows the need for detailed and advanced energy demand modelling techniques that would enable a more focused assessment of various energy policies. As a result of these efforts more quality calculations could be made, not only for the long term energy demand, but its effect on the economy, environment, creation of jobs etc.

The main question that the author asks is: what is the effect of implementation of various energy policies on the long term energy demand, primarily, but also what the effect on the environment and the national economy is.

---

[1] Vuk B et all, Energy efficiency policies and measures in Croatia, ODYSSEE MURE project, 2012

1.2 Research motivation

1.2.1 Research question

Next 40 years present a big challenge, energy planning wise. From one side, conventional fuel reserves are limited and are going to run out at some point [23]. The EU is facing a challenge with the security of energy supply and needs to find viable pathways to decrease this threat. The EU economy is looking for a way to use this situation to its advantage, through state of the art research and production of future energy technologies, both renewable and conventional ones [24]. Finally, environmental aspect is significant to all future energy planning challenges.

Considering all mentioned facts, planning future energy demand is the first step towards sustainable energy systems. Strict EU targets for 2020, 2030 and 2050 ask for a new way of thinking when it comes to energy planning, both on the demand and supply side. One of the top three ranked mitigation options in the future period will be the demand-side measures comprising energy conservation and energy efficiency improvements [25].

On the other hand, a new approach in modelling energy demand is necessary, especially in order to quantify and "catch" intensive future energy policy. Classical energy demand modelling, based on historic top down approach will not be enough anymore.

The main questions that are going to be the focus of this research are:

a) How can different energy demand modelling approaches be used in the quantification of energy policy implementation
b) Identification of various influencing energy policy measures
c) Quantification of identified energy policy measures
d) What is the effect of EU energy policy measures on long term energy demand
e) Comparison of various scenarios and policy options
f) How can energy demand strategies help in lowering energy dependence
g) What are the side effects of strategic energy demand planning

Where:

a) How can bottom up energy demand modelling, in comparison to top down approach, increase the level of results accuracy, and intensify energy policy implementation and identification of additional policy measures.

b) Every economic sector has its specifics, thus every economic sector would have various policy measures influencing future energy demand. Identification of energy policy measures is based on current ones, which are usually found in the current legislation or financial mechanisms that are already in place. On the other hand, it is very important to recognize future policy measures that are currently not in place, but are expected.

c) Is it possible to calculate real figures behind every policy implementation? If so, what would be the procedures, both from an energy point of view and strictly mathematical.

d) After implementing energy policy and calculating its effect, what would be the impact on the whole national energy system?

e) When summarizing all policy measure effects, the intention is to present national energy wedges.

f) How can energy demand planning help in lowering energy dependence of a country, and to what extent?

g) What is the result of energy demand changes? What is the impact on the environment, economy etc.?

To answer these questions, the Republic of Croatia will be used as a case study.

1.2.2 Research motivation

Probably the main motivation for this research is to provide a quality input data for energy systems modelling. Usually, until now all input data regarding energy demand forecast for the case of Croatia were done as a simple top down econometrics. Fundamentally, energy demand planning should be connected to the supply side, since the bottom up information (e.g. the number of electric vehicles [26]) drastically changes the way this demand is met. We can say that energy system has the capacity for self-regulation [27].

Another motivation for this research is the lack of long term energy demand forecast for Croatia. One of the rare studies of Croatian final energy demand till 2050 can be found in the EU GHG emission trends till 2050. The study used a PRIMES energy planning model which predicted an increase in final energy demand of 36.8% in the year 2050, in comparison to the reference year 2013. One of the main reasons for this is the model's orientation to socioeconomic factors and indicators with a lower level of details on energy policy implementation [28]. The other available study is the National Energy Strategy [29]. In this case very simple top down approach was used, which led to overestimated energy demand figures in the years 2020 and 2030.

Next, the author wanted to upgrade the existing in house supply side models with detailed energy demand modelling philosophy and results. The first intention was to use Croatia as a case study, but generally the developed methodology could be applied globally and used for other countries.

Also one of the motivations for this research is to quantify actual energy policy measures and the energy saving they create. By using bottom up methodology for the US, McKinsey estimates that GHG emissions in the year 2030 could be reduced by 30% at marginal costs below $50/tonne [30]. Authors in [31] have calculated that end-use energy consumption in the year 2020 in the US could be reduced by 23% with savings exceeding costs.

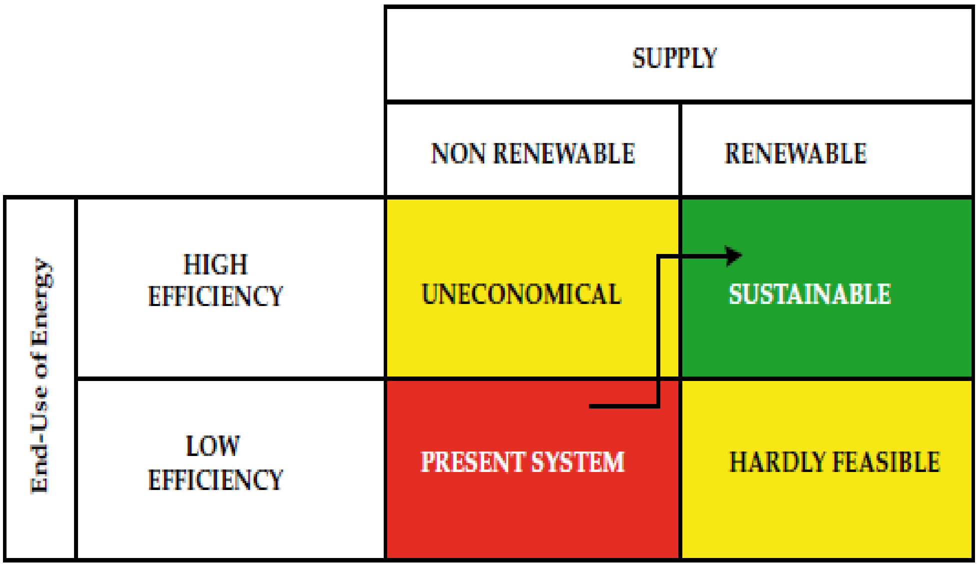
The author of this thesis wanted to create a national model and test it on Croatia in order to analyse cross sectoral connections as one of the most interesting issues when dealing with national models. Other researchers investigated cross sectoral connection and concluded that this connection is necessary due to various dependences (e.g. HGV modelling based on a property bubble [32]).

1.2.3 Energy system and long term energy planning

Today, strategic energy planning that takes into consideration all available resources, technologies, social and economic aspects, the interlinkages between various energy systems is a must. The first step is knowing your energy system, national or regional, in order to establish baseline relations which will be later on used in the analysis. This includes; sectoral analysis [35], capacity mapping, RES potential [34], specific energy intensities and energy balances [33] etc. A few „global“ parameters, usually macroeconomic, are the most commonly used in the energy planning process. First, a relation between various economic variables, such as the GDP, and energy consumption can be drawn. Next, demographic aspect is the most common driver in energy demand planning. Negative population trends will heavily influence future energy policy, and based on that it is necessary to describe, and possibly quantify them. The European Union, as well as Croatia, is faced with a continuous process of population getting older. As a consequence, the EU will have a shortfall of labour force, lower energy demand needs, lower energy capacity requirements etc. [36]. Energy consumption per capita, from various energy sectors to various end uses, represents an important energy demand planning parameter, and it should not be misused. Assumptions and results from demographic analysis might be misleading if taken superficially. For instance, the increase of standard might lead to the increase of specific living space which will in the end induce an increase of energy consumption [37].

This fact does not mean that further energy efficiency improvements should not be encouraged or taken into consideration when doing energy demand planning. Negative demographic trends do not mean giving up on structural changes in approaching energy efficiency since energy consumption per capita is just one small variable determining the energy efficiency of the whole system. Going back to the economic aspect; one of the primary variables that needs to be addressed is the energy intensity which could answer the question of national energy efficiency. A subject of the energy planning process will be the production capacities and their export/import components. Energy dependence, expressed with its import component, can be further compensated with classic diversification of the fuel mix, in order to create an optimum. As another important factor connected to the diversification of the fuel mix is the ability to withstand various fuel price shocks that can happen on the market. As an upgrade to the production capacity planning is the planning of transmission lines, if talking about electricity, or any others that might be used in the supply of fossil fuels.

Legal framework which is in line with the limitations, in both cases, should be observed as the first step towards energy efficiency systems (Figure 5). The main objective for the EU in the 2050 is the final transition from non renewable and relatively low efficiency system to the one which is very efficient and renewable oriented.



		SUPPLY	
		NON RENEWABLE	RENEWABLE
End-Use of Energy	HIGH EFFICIENCY	UNECONOMICAL	SUSTAINABLE
	LOW EFFICIENCY	PRESENT SYSTEM	HARDLY FEASIBLE

Figure 5 Transition to a sustainable energy system[2]

Complementarity of energy efficiency and renewable energy sources in achieving this transition can be seen in Figure 6. If we allow current trends to continue our energy demand becomes unsustainable, making it difficult for sustainable energy resources to satisfy the demand. But, if we apply measures of energy policy which will result in a decrease of energy demand, we allow sustainable energy resources to satisfy that demand.

---

[2] International Energy Agency

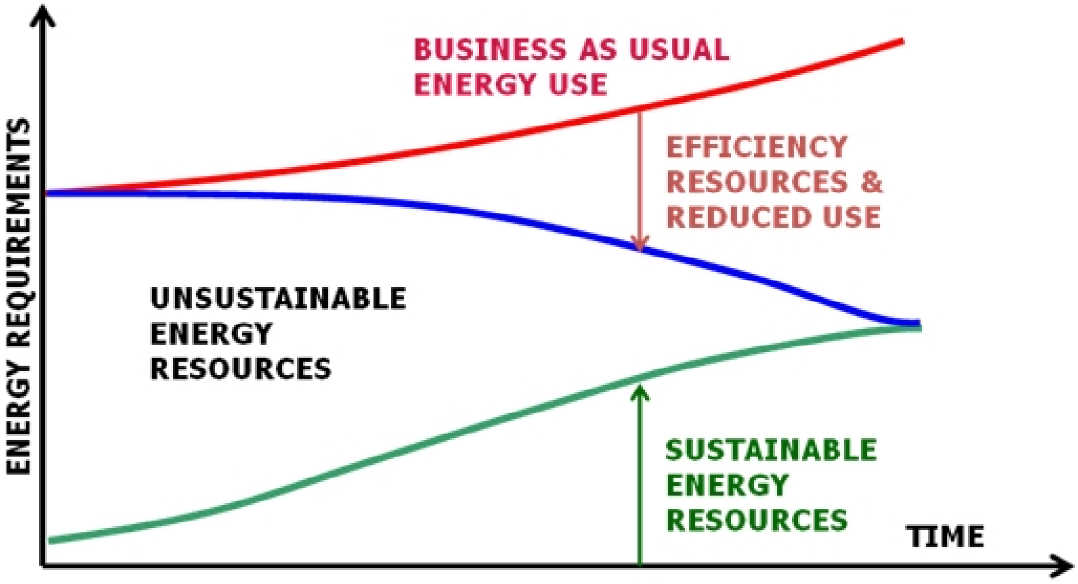


Figure 6 Interaction between energy efficiency improvements and renewable energy sources[3]

The next level of mechanisms influencing energy demand is the fiscal segment, which has a job of easing the transition to a low carbon society. Very often, at the beginning, these measures may not be at the level of economic viability [38][39]. In Croatian case this fiscal segment is possible through strong investment in energy efficiency, whether through various credit lines or tax reliefs or through strong incentives to equipment manufacturers. For instance; in the transport sector fiscal segment can be expressed through a favourable system of taxation for very efficient vehicles or alternative ones.

Based on these two simple examples a connection between demand and supply can be seen. Planning of advanced energy systems requires a new approach in energy demand planning. In order to balance a system with lower energy demands, in combination with high share of renewable energy sources, a higher flexibility is needed [40] [41]. A part of that flexibility can also be found and modelled on the demand side [42]. In this case the authors are assessing flexible time frames of electricity consumers in both residential and industry sectors.

Unfortunately, this fact often results in ideological conflicts between the modellers focused on the supply side and the ones focused on the demand side. Strategic energy documents in Croatia are usually focused on the analysis of the energy system, very often neglecting the energy consumption forecast, which in the end leads to overestimated figures [29].

---

[3] Blair Hamilton, Managing energy demand, 2009

1.2.4 Demand/Supply interaction

Energy planning should be observed as an integral analysis in which certain interaction between planned demand and planned production capacities, needed to satisfy that demand, exists [43][44]. Interaction of these two components will give the answer to which option is the best for the observed energy system, whether from the economical, technical or purely ecological point of view. One of the key issues future energy systems need to face is the increase in electricity demand, as a result of all sector electrification effect [45]. This effect could be favourably observed since electricity can be considered the cleanest and the most valuable form of transformed energy. Increase of electricity demand should not be observed through the prism of final energy demand, which is usually used in the classical political debates. Just the opposite, this phenomenon should be observed through the prism of primary energy. Even more accurate analysis should be done by following the full energy chain; from useful to primary energy. Classic example can be emphasized through the buildings sector, where a strong electrification of "traditional systems" is expected. This does not relate to the cooling systems, which are traditionally electrified, but to the heating systems. A big development in the technology, together with a strong legal framework for energy efficiency buildings leads to significant energy savings on both useful and final energy demand levels [46]. Development of new technologies can result in the faster implementation of heat pumps, as high efficient technology, from one side and with legal restrictions regarding electrical resistance heating from another.

Prerequisite for these assumptions, when it comes to the buildings sector, is a heavy future investment in the buildings renovation, together with the new standards for building new buildings [47]. The fact that the EU policy on energy efficient buildings[4] regulates nearly zero energy buildings in the period after the 31st of December 2020 means a totally new concept in this sector [48].

Another example is the electrification in the transport sector, especially personal vehicles segment. This will result in a high impact for the power sector, both electricity generation and storage [26]. Nevertheless, the advantages of this effect are numerous; less pollution in urban areas, lower energy dependence on fossil fuels, lower GHG emissions etc. Finally, when

---

[4] Energy Performance of Buildings Directive

modelling transport sectors of the future, the constant increase of energy efficiency and the development of internal combustion engines needs to be stressed out. This is mostly a result of a constant EU policy towards decreasing CO_2 emissions, which at the end pushes the producers towards more energy efficient solutions [49][50].

One of the main objectives of this research is to try to quantify as many mechanisms influencing energy demand as possible. With this approach to demand-side modelling, higher-quality data and results can be obtained and used as input data for all future research on advanced system analysis [51][52].

1.2.5 Demand modelling philosophies

When analysing data inputs and methodology, literature recognizes two main principal approaches: bottom-up and top-down approach [53][54]. A typical bottom-up approach considers separate technologies and energy balances for individual consumers, while their summarization leads to the desired results [65]. This approach focuses on the energy system as such, and not on its interaction with the economy as a whole. A typical top-down approach views the economy as a whole, its results are based on the analysis and calibration of historical data, while the main idea is to establish the relationship between energy consumption and GDP. The focus is on the mechanisms and processes that are on the market, rather than on the technology itself. In this approach, there are several different sub-approaches such as computer models of equilibrium, econometric models [55], and several hybrid models that combine information technology and economic processes [56]. It is often difficult to tell the difference between these approaches and some of the models in the literature can easily be classified under one and the other approach.

IPCC AR4 [57] report uses top down terminology for all models that have the integrated approach while the bottom-up terminology is used for all the models that focus on individual technology. Based on the literature, bottom-up models generally predict a lower energy demand, with a better description of energy efficiency measures, as opposed to top down models. It is here where the so-called split in energy efficiency (energy efficiency gap) [53] is detected. The gap is often explained by a combination of bottom-up information with unrealistic discount rates. The second level of the bottom-up modelling refers to the phase-out or phase-in of certain technologies which cannot be modelled by the energy efficiency increase factors. An example of the buildings and transport sectors can be taken as a good example, where the entry of heat pumps and electric vehicles has a jump of energy efficiency by a factor of 5. In the literature a combination of these approaches is used, which typically have a top down approach but also use the bottom-up information to define some of the parameters [58]. There are even several attempts to even cross link the existing top down bottom up models (TIMES and CGE GEM-E3) [59].

The authors in [60] analysed AR4 report and compared modelled results from both top down and bottom up studies. The conclusion was that the global emission reduction potential was very similar, however, among sectoral models significant differences were found. The reason for this was inconsistency with the baselines.

There are various cases of incorporating technological progress in energy-economy models and its effect on long term energy demand projections [61]. However, the authors in [62] showed the paradox of energy demand planning based on economic parameters because in order to achieve the challenging mitigation scenario, they had to set hypothesis which were hardly possible, such as zero or negative economic growth.

One of the valid claims in favour of top down approach is the fact that energy policy does not just influence the energy system and should therefore be analysed within an economy-wide framework [63]. However, top down econometric approach is an acceptable approach only for the developing countries which have, and expect, a high economic development, together with high industry growth. In the case of developed countries, such as the EU, this approach is unacceptable, especially for the long time energy demand planning [64].

Another very common categorization, present in the literature, based on different philosophies in determining the long-term energy consumption recognizes three approaches; econometric models, models focused on the end-user and hybrid models [65]. The econometric approach is a quantitative method that establishes the interdependence between dependent and independent variables by using statistical analysis of historical data, while the models focused on the end-user are observing energy consumption on a non-aggregated level.

1.2.6 Energy demand modelling

In the process of energy demand modelling, the future cannot be programmed, but it can be predicted based on various current or future indicators, learning curves, policies etc. In this process, scientific methods need to be applied in identification of various mechanisms influencing future energy demand. Also, information and variables need to be chosen, and not created, in order to achieve the highest level of accuracy. Very often, collected data needs to be summed, averaged, extrapolated or combine the complexity of various methodologies. Energy demand planning can only be acceptable with realistic evaluation and analysis of final results [66][67].

As a result of an energy demand planning process a detailed energy system, capable of calculating electricity demand, heat and cooling demand, transport fuel demand and interaction between sectors and energy forms, is available. In order to follow advanced system analysis, certain energy demand parameters could be calculated on an hourly basis.

The energy demand forecast was usually done by doing trend analysis combined with various extrapolation techniques in order to calculate simple input parameters for the analysis of the energy system. Today this approach is unacceptable because it does not allow the quantification of various mechanisms and policies influencing energy demand which are not historically describable. Due to new regulations regarding energy efficiency, environment, renewable energy sources, EU countries are expected to decrease their energy consumption in the future. The specific objective of the entire EU is set (Figure 7) and it is important to model various energy policies in order to calculate pathway to achieving those challenging tasks.

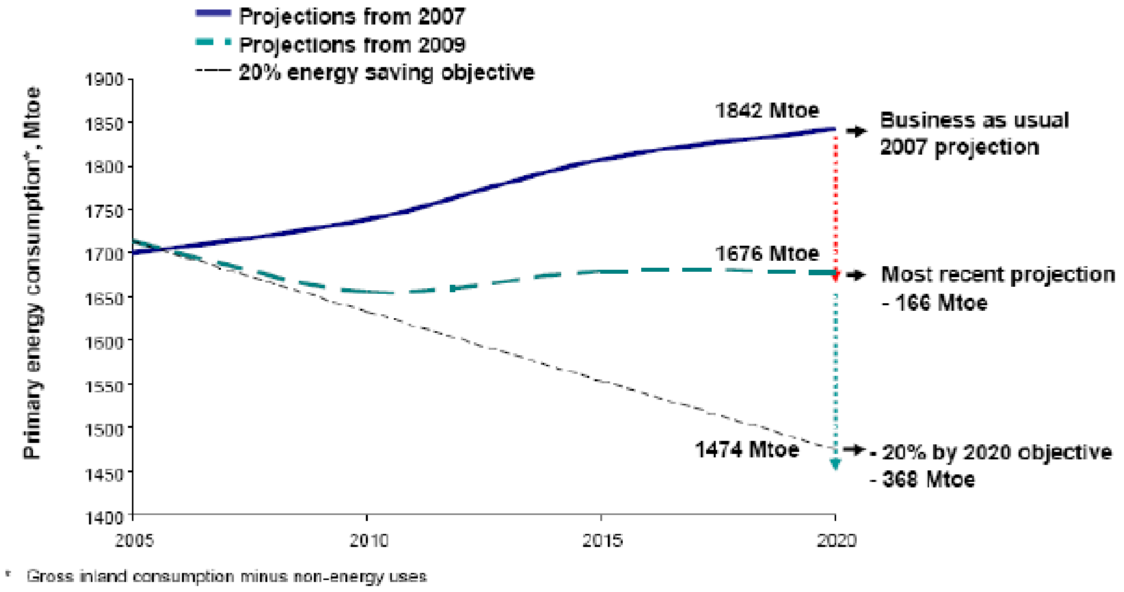


Figure 7 EU 2020 consumption projections[5]

One of the key issues in the energy demand planning process is not to show what will happen in the future, but to show what might happen if certain assumptions, learning curves and policies are implemented. In this case, scenario approach is the best option in order to show how different policies influence the future energy demand. For example, how can a total ban on electrical resistance heating for new buildings influence the future demand [37].

European framework

EU 2020 objective is to decrease its GHG emissions 20%, or 30% if the right conditions are met, in comparison to 1990, to increase the share or renewable energy sources in final consumption to 20% and to increase its energy efficiency 20% [68]. This energy-climate policy is done through various directives, regulations, national laws and bylaws.

Total GHG emissions of the EU-28 decreased by 1% between 2011 and 2012, based on approximated GHG inventories from 18 member states and the EEA. If we look at the scope

---

[5] Source: European Commission

of the EU's climate and energy package, including emissions from international aviation, the reduction of 2012 EU emissions is about 18% compared to 1990 levels. Based on this the EU is close to reaching its 20% reduction target, 8 years ahead of 2020 [69]. After 2020, the aggregation of national projections shows EU GHG emissions are expected to continue decreasing. This time the decrease will be at a slower rate. With the current implemented measures, GHG emissions would decrease by only one percentage point between 2020 and 2030 (reaching a level 22% below 1990).

If the EU member states would implement additional measures they would reduce emissions in the period 2020 to 2030 to 28% below 1990 levels. However, these anticipated reductions between 2020 and 2030 are still not enough if compared to the cost effective 2030 milestone of reducing the EU emissions by 40%[6]. The EU's commitment to achieving a reduction of emissions by 80% to 95% by 2050 compared to 1990, as agreed by the European heads of state and government, will require enhanced efforts from member states. The EU target on 20% RES share will probably be achieved, and one of the main reasons for this claim is the RES capacity installed in the last few years. In 2010 more renewable electricity capacity was installed in the EU than ever before. In the 2008 13,3 GW were installed, in 2009 17,3 GW and a record of 22,6 GW in the year 2010 [70]. RES contributed 13% of gross final energy consumption in the EU-28 in 2011. The EU has therefore met its 10.8% indicative target for 2011–2012 and is currently on track towards its target of 20% of renewable energy consumption in 2020. EU-28 is on a good track towards the level of ambition prescribed by the EED[7]. Collective primary energy consumption in 2020 is expected to be close to the level required by the EU objective which is 1483 Mtoe, but will remain insufficient to achieve the 20% energy efficiency target [69].

New EU energy strategy, signed in Brussels in 2010 is therefore concentrated on five priorities; creating energy efficient Europe, building pan-European integrated electricity market, achieving a high level of energy security, achieving the EU domination regarding energy technologies and strengthening the foreign dimension of the European energy market [71].

---

[6] European Commission , March 2013

[7] Energy Efficiency Directive

Beside energy strategy, numerous directives and regulations have been created, in various fields such as energy efficiency, transport or renewable energy sources. Some of the most common energy legislation used in the energy demand planning process includes:

Energy Efficiency

- Directive on end-use energy efficiency and energy services - 2006/32/EC
- Energy Performance of Buildings Directive - 2010/31/EU
- Energy Efficiency Directive - 2012/27/EU
- Ecodesign Framework Directive - 2005/32/EC
- Energy Labelling Directive and delegated Regulations covering: lamps and luminaires - 2010/30/EU
- Office/street lighting regulation Commission - (EC) No 347/2010
- Lighting Products in the domestic and Tertiary Sectors regulations
  - (EU) No 347/2010
  - (EC) No 859/2009
  - (EC) No 244/2009
  - (EC) No 245/2009
- External power supplies regulation - (EC) No 278/2009
- TVs regulation (+labelling) regulation - (EC) No 642/2009
- Electric motors regulation – (EC) No 640/2009
- Freezers/refrigerators regulation - (EC) No 643/2009
- Household washing machines regulation - (EU) No 1015/2010
- Household dishwashers regulation - (EU) No 1016/2010
- Industrial fans regulation - (EU) No 327/2011
- Air conditioning and comfort fans regulation - (EU) No 206/2012
- Circulators regulation - (EC) No 641/2009

Transport

- Regulation on CO_2 from cars - (EC) No 443/2009

- Regulation EURO 5 and 6 - (EC) No 715/2007
- Fuel Quality Directive - 2009/30/EC
- Regulation Euro VI for heavy duty vehicles - (EC) No 595/2009
- Regulation on CO_2 from vans - (EU) No 510/2011
- Eurovignette Directive on road infrastructure charging - 2011/76/EU
- Directive on the Promotion of Clean and Energy Efficient Road Transport Vehicles (in public procurement) - 2009/33/EC
- End of Life Vehicles Directive - 2000/53/EC
- Mobile Air Conditioning in motor vehicles Directive - 2006/40/EC
- Single European Sky II - COM(2008) 389 final
- Directive on inland transport of dangerous goods - 2008/68/EC
- Third railway package Directive - 2007/58/EC
- Directive establishing a single European railway area (Recast) - 2012/34/EU
- Port state control Directive - 2009/16/EC
- Regulation on common rules for access to the international road haulage market - (EC) No 1072/2009
- Directive concerning social legislation relating to road transport activities - 2009/5/EC
- Regulation on ground-handling services at Union airports Part of "Better airports package"
- Regulation on noise-related operating restrictions at Union airports Part of "Better airports package"
- Directive on the sulphur content of marine fuels - 2012/33/EU
- Labelling of tyres regulations - (EC) No 1222/2009

Also member states are passing national laws and bylaws focused on decreasing energy consumption and meeting overall objectives. For instance, in Austria single fine of 25€ is paid per gram of CO_2 above 170 g CO_2/km, while for the purchase of an alternative vehicle a 500€ incentive could be used. In Germany a yearly tax of 2€ per a gram of CO_2/km is in place while the cars below 110 g CO_2/km and electric vehicles are exempt from that tax [72]. Beside these examples most of the EU member states have implemented various taxations, financial schemes in the buildings sector which are more strict and restricted than the EU ones.

The Republic of Croatia has taken over the EU objectives for the year 2020 (decrease of GHG emissions and energy consumption together with the increase of RES share). In order to achieve these targets numerous laws, bylaws, regulations such as the Regulations on the use of renewable energy sources and cogeneration, the Building Act, the Energy Act, the Environmental Protection Act, the Energy Efficiency Act, the Thermal Energy Market Act and many others have been passed. The main problem, unfortunately, presents the implementation, verification and monitoring of these legal frameworks.

The Republic of Croatia will probably achieve its goals in the year 2020 in the field of energy consumption reduction and GHG emission reduction [73]. But this will not be the result of the extensive policy implementation and national efforts, but a result of deep economic crisis, which resulted in an overall decrease in energy consumption, especially in the industry sector. Croatia will need to invest significant efforts in order to achieve targets and obligations that were taken over with the accession to the EU. The biggest challenge will be in the decrease of various non technical barriers that are holding back structural changes, both in energy efficiency and implementation of renewable energy sources.

Europe in the year 2050

Greenhouse gas emissions of EU-27 have been estimated to around 16% lower in 2009, if compared to 1990. In the same period the EU economy grew by around 40%. Based on this data a decoupling trend can be detected, where the emission went down and at the same time the economic growth has been achieved (Figure 8).

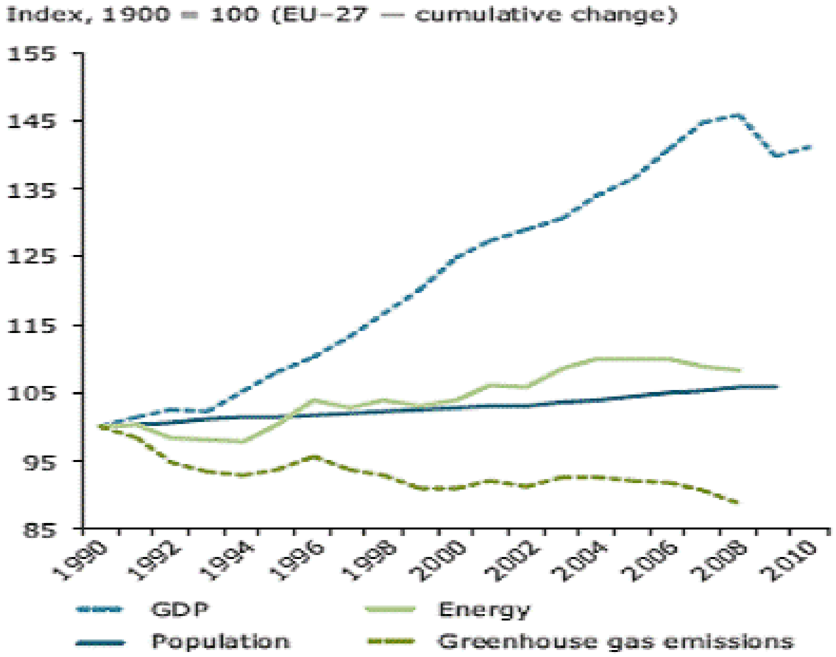


Figure 8 Comparison of EU-27 GDP and energy consumption[8]

Looking forward, final EU objective in the year 2050 is a decarbonised Europe [39]. There are a lot of scenarios trying to calculate this transition; using carbon capture storage, nuclear energy option, high penetration of renewable energy sources, but also a wide range of energy policies focused on energy efficient technologies and procedures. Because of the expected increase of electricity demand, as described in the previous chapters, special emphasis will be given to energy management and the decrease of energy intensity which would result in a lower energy demand. Based on the European Commission scenarios the EU would consume 1050 Mtoe with a potential decrease to 735 Mtoe by applying strict regulation. Renewable energy sources share in gross final energy demand should be from 55% to 97%, depending on the scenario [74]. This decrease in energy consumption and increase of renewable energy sources share would mean significant GHG emission reduction (Figure 9) as well as energy independence for Europe in the year 2050.

---

[8] EEA, SOER 2010, European environment State and Outlook 2010

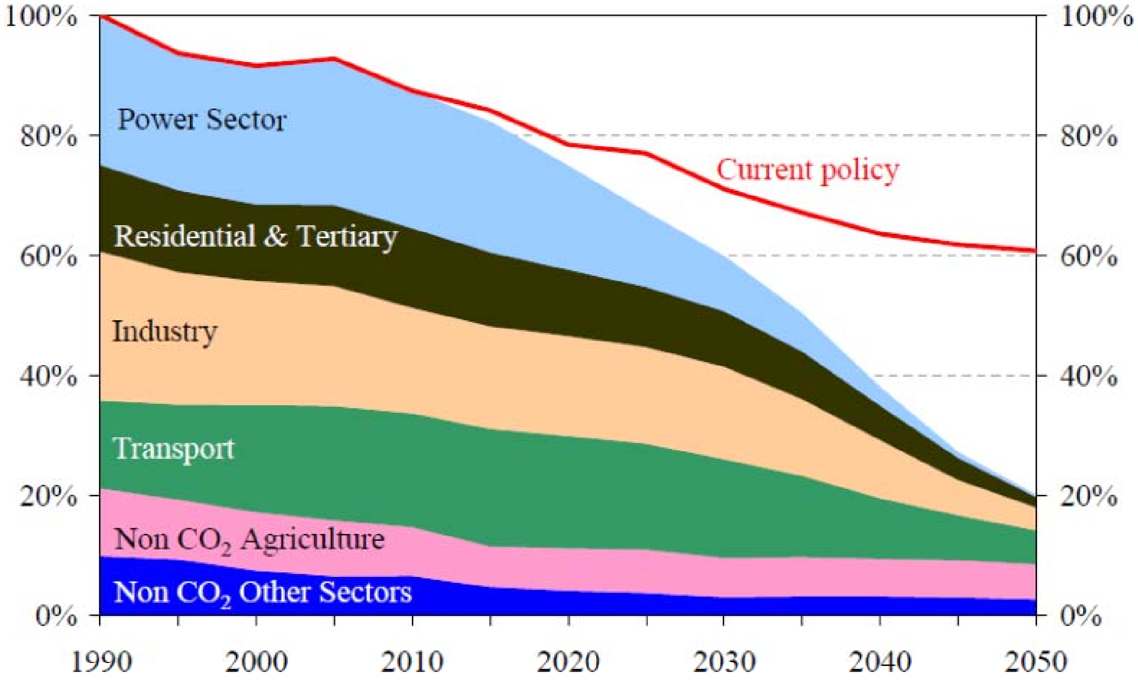


Figure 9 EU GHG emissions towards an 80% domestic reduction [39]

National energy Demand model

The proposed research refers to the bottom-up end-use models, used for long-term energy demand planning, which take into account the technologies that are at the stage of research and development, and may have a major role in determining future consumption. They project consumption at the level of end-users and based on the estimated standards of energy consumption for a particular activity, future energy consumption can be determined [75] [76]. Such models are extremely suitable for long-term energy demand forecasts, but they require a very high level of necessary input data, both in quantity and quality [77]. In the literature, models of certain economic sectors are found, which can then be incorporated into a comprehensive model for the planning of energy consumption at the national level [78] [79]. Every economic sector has its specific properties, which should be described and quantified in the engineering bottom-up model [65]. In the literature, the national sectoral classification can be described with three main sectors; buildings, industry and transport [65].

For the purposes of this thesis a six economic sectors bottom up model was developed. The National energy Demand (NeD) model presents a highly detailed model whose main purpose is to show how future energy demand is influenced by various mechanisms. For the three main sectors, “stand alone” models were created (HED model – Households Energy Demand, EDT model – Energy Demand of Transport and IED model – Industry Energy Demand) and implemented into the NeD model. Other three economic sectors; services, construction and agriculture, have not been created as “stand alone” models, but were simply already integrated in the NeD model. Engineering bottom up energy demand models, which focus on end users, usually can have a better overview and evaluation of potential future energy savings. End user demand is affected by the cost of energy, but more importantly, it is affected by other mechanisms such as legislation, financial schemes, technological development, climatic conditions, etc. This feature is crucial in order for the new energy policies and strategies to be created and tested [80]. The downside of this approach is the extensive input data that has to be gathered and systematised [81] [82]. This is especially problematic for the countries with data deficiency, both statistically and energy balance wise. In those cases building a bottom up model can be very difficult. Bottom up approach, focused on end users, can be described with the following general steps, as defined by the UN (1991) and the IAEA (2006) [83]. The first step would include the identification of relevant end use categories and their categorization. Afterwards, a detailed analysis of influencing factors is necessary to set the mathematical relationships. Next, the reference year analysis is a must because it allows testing of the methodology and mathematical relationships. Finally, the scenario approach needs to be applied to quantify all the modelled measures and mechanisms.

Throughout this thesis, the literature review regarding modelling approaches, specificities, results, etc. will be given for the three main sectors; buildings (households and services), transport and industry.

Households sector

With such an importance to the Croatian energy balance [84], the households sector presents a significant opportunity for energy savings and implementation of renewable energy sources in the upcoming period. According to [85], decentralized energy generation, with special emphasis on households, would become an important factor in the wider introduction of renewable energy sources. Energy efficiency wise, years of negligence, lack of building regulations and disobeying current building codes has led to inefficient building stock with high energy consumption as a result. However, certain improvements in this field are noticeable in the last years. These trends are mostly influenced by the Croatian accession to the EU. Consequential to this process is the transposition of all the EU legislation regarding energy performance of buildings. As in the Italian case, Croatian decision makers need to perceive the benefits of current building stock improvements and the introduction of low energy buildings as a mechanism in achieving significant energy savings [86]. This should be observed as a great opportunity since it will allow further development of the Croatian economy and better energy management in the households sector. Although financial benefits, which would be the result of the EPBD[9] implementation in Croatia, are not the subject of this research, their impact on the country's economy could be significant [87].

Considering all possible measures that could be implemented in Croatian households sector, it would be very important to know what trends to expect regarding future energy demand. This would also be important in terms of satisfying international commitments regarding energy consumption and GHG emission [88] as well as planning future energy systems.

One of the key elements of this research is to analyse future energy demands depending on most interesting characteristics specific to the households sector: available floor area increase, energy efficiency improvements and building code regulations. There are other elements whose influence on future energy demand could be significant, like occupants' activity and their behavioural patterns [89]. These elements can be very interesting in cases where heating demand is not predominant [90]. This research will present the connection between above mentioned elements and final energy demand of the households sector. In order to quantify this connection a Households Energy Demand Model (HED Model) has been developed [37].

The authors in [37] showed how a strict application of energy policy (e.g. part of the legislation that applies to new constructed and the renovation of old buildings) impacts on the long term reduction of final energy consumption in households. The model is based on a bottom up approach analysis in order to quantify and describe all the key elements influencing energy demand in a more concise way [91]. Because of that, technology impact, as well as energy policy, could be quantified and later on compared.

Based on the available literature, statistical and engineering bottom up modelling are the two most common approaches [92]. While statistical bottom up approach is not the focus of this

---

[9] Energy Performance of Buildings Directive

research, we will just mention its value in processing vast quantity of historical data, usually using regression analysis. But when considering any kind of technology impact, bottom up analysis based on engineering approach that could describe building physics is needed. This includes different referent units, from individual sample buildings till wider geographic units, like neighbourhoods [93]. The HED model works with three basic referent units used for energy consumption calculation: newly built, refurbished and existing “old” units. All three units are represented with available floor area and are distributed geographically in 21 Croatian counties. In order to quantify each of the proposed measures, the authors have focused on the useful surface areas modelling. By using thermodynamic relations they receive a detailed geographical distribution of the cooling and heating energy demand on the useful energy level.

At the same time the HED model uses different statistical components, which are based solely on empirical information, which could classify it as a hybrid model [94][95]. If we compare it with the IEA World Energy Model specific for the households sector [96], many methodological connections can be found. Calculation logic is similar when compared to the HED model, in terms of the end use distribution and partially regarding activity variables. Based on the IEA methodology, socioeconomic drivers are defined in a far more detailed way which allows better interaction between energy demand and prices.

One of the issues, found in the literature, connected to household bottom up models is the behavioural influence on energy demand and its description and quantification. Bottom up models often do not model, but just assume behavioural impact on energy consumption, which is a clear shortcoming of this approach [91]. The HED model is in line with this statement with one exception which is the demographic parameter. Based on the demographic fluctuation and its geographic distribution, the HED model has an initial possibility to describe occupants’ activities, but further development is necessary. Proposed action could go towards better integration of top down and bottom up approaches with the integration of possible macroeconomic indicators. Sectoral integration and interaction could present an obstacle when considering significant quantity of input data. Sectoral approach gives a more detailed overview of basic modelled data, such as building stock, but it lacks the capacity for inter-sectoral interaction [97]. But since the HED model does not work as an optimization model this shortcoming will not be an issue in our case.

More detailed application of top down methodology or its fragments were considered when developing the HED model, but its aggregated approach would not allow a precise combination and quantification of different elements and mechanisms that would influence energy demand [91].

The HED model is focused on calculating heating and cooling demand as well as energy demand for house appliances, hot water and cooking. One of the main intentions was to show how renovation paste can influence on future energy demand. In our case intention was to show the influence of new nearly zero energy buildings and old buildings renovated to nearly zero energy standard on final energy demand [98]. With such a detailed model different improvements regarding energy efficiency as well as different technologies and fuel mixes could be presented and discussed. The idea is to connect demographics and available floor area of the whole households sector with its final energy demand. Based on this connection different scenarios and approaches could be presented. The HED model can be used for any other country and its households sector, considering all the specificity of that country. The model works based on the population data, floor area, specific climatic regions which can all be imported into the model. Since the HED model is an MS Excel based, every user can modify all the categories based on their needs. The same is with specific energy efficiency improvements. The only shortcoming of this approach is the extensive input data required, which could present a problem for using the model for a different country.

The authors in [99] and [100] showed how important technological development and energy policy are for the modelling of the building sector. The results show that the two above mentioned parameters may be more important than the behaviour and lifestyle of the users, when analysing energy consumption. The authors showed that the total final energy consumption in the EU in 2050 could be reduced by 50%, compared to 2005, if the growth in energy efficiency is greater than 2% per year. They also showed that the EU objectives in terms of CO_2 emissions can be achieved only if we rely on electricity and district heating coming from low carbon technologies. In [101], the authors divided the bottom up models into statistical and building physics based, while their interest was in the second ones. They stressed out major problems and issues with these models. One of them is the lack of publicly available input data and the other is the uncertainty of socio-technical drivers (e.g. how people use their energy).

Services sector

In [102] the authors developed a similar bottom-up model, as in [37], to predict the long-term energy consumption of the tourism sector, with a difference in the outer shell modelling approach with more simplified thermodynamic calculation. The main reason for this is the significant limitation in accessing the input data, which are critical to the functioning of the model.

Transport sector

The transport sector, as one of the most propulsive sectors, represents an important contribution to the energy balance in Croatia. Over the past ten years, the final energy demand of the Croatian transport sector has grown by more than 70%, which can be explained by constant fleet expansion, followed by high economic growth [84]. Another important factor that has induced increased energy consumption is the increase in capital infrastructure, especially modern highways. To plan ahead and model future energy systems, predicting future energy demand seems as the first logical step [103]. As already mentioned, high significance of Croatia's energy balance makes the transport sector one of the most interesting to analyse [104].

One of the intentions of this research was to propose a clear and rational energy demand model. Unfortunately, there are only a few long-term energy demand scenarios that involve the Croatian transport sector. The most important one is the official National Energy Strategy, which provides an overview of the country's energy demand scenarios using a sectoral approach. It offers future energy demand projections for all economic sectors for the years 2020 and 2030 [105]. In the results section of this research, the results obtained from this study will be compared with the official National Energy Strategy for the years 2020 and 2030.

Through this research the author has constructed a bottom-up long-term energy demand planning model (EDT model), which was applied to the Croatian transport sector as a case study [26]. In the analysis, the authors have shown that the significant savings in the final energy consumption as well as CO_2 emissions can be expected through three main mechanisms: the increase of energy efficiency of internal combustion engines (in correlation with the EU directives); the electrification of transport segment in which it is technically feasible, in particular the segment of passenger cars and the intermodal; and the gradual transition from energy-intensive modes of transport (goods and passengers) to the ones less intense.

The EDT model focuses on vehicle population dynamics that includes a lifetime, as well as entry and exit of certain types of vehicles. Vehicle population dynamics are based on the new regulations and the expected development of the technology. In the passenger car segment, the most important is the entry of hybrid and electric vehicles, as well as the gradual implementation of biofuels.

The EDT model can also be applied to any other country and its transport sector provided that it can follow the input data pattern. For the purposes of this research, the EDT model was structured to predict the future energy demand till the year 2050. Different approaches were considered for the development of this model; structural time series model [106], neuro-fuzzy inference system [107], log-linear regression models [108], genetic algorithm models [109], but a bottom-up approach was selected as the most suitable one because it allows the users to have a wider view of the whole sector and provides the opportunity to implement different types of mechanisms, such as technology switching [110], energy efficiency improvements [111] or legal regulation [112], in a more detailed way.

A top-down approach was incorporated and partially implemented using the EDT model, but only to observe the energy demand projection left to economic growth. Similar models and studies have been performed to compare the two approaches (top-down and bottom-up) and to determine the best possible solution in the case of; gasoline price fluctuations [113], demographic fluctuations [114] and technology switching [115]. In [116] the authors have developed and used a hybrid model to explore how divergent definitions of costs and different assumptions about technological change could affect the estimated long-run costs of GHG abatement in personal vehicles.

The EDT model has five transport subsectors: road, rail, air, sea-river and public transport. Because the model is an MS Excel based, additional subsectors can be added or some of the existing ones can be removed. A separate mode is created for each subsector to describe all of the specific factors influencing future energy demand. To calculate the total final energy demand of the transport sector, the final energy demands of all of the subsectors are summed in the model.

In the case of Croatia, certain boundary conditions and specific factors were incorporated to describe the country's transport sector. These factors include coastal transport and special coverage of urban public transport. One of the major boundary conditions was the exclusion of bunker fuel in both air and sea coastal transport. For the purposes of this research, the official Croatian energy balance [84] and statistics [36] were followed to provide a consistent basis for all the future research and results.

In the transport sector, it is interesting to analyse the relationship of energy prices on consumption. The authors in [117] showed that a moderate increase in oil product prices will not result in reduced energy consumption, and that this is only possible with a strict energy policy that relates to increased energy efficiency. For the purposes of that analysis, the authors have developed a simple bottom-up model, which was used to analyse the possibilities of reducing CO_2 emissions through an intermodal transition, from energy-intensive modes of transport to less intensive.

The authors in [118] concluded that the integrated policy approach, in the case of the transport sector, which considers both demand and supply, is far more effective than any single policy intervention. Because of that this approach is necessary for achieving a strict 80% carbon reduction target.

Industry sector

In the industry sector the authors in [119] identified four main parameters that are crucial in the estimation of energy consumption in bottom-up models. Import/export component determines the share of domestic industrial production, which is directly related to the energy consumption. Another criterion is the possible making or disappearance of a certain type of industry. Technology development and energy efficiency are extremely important in the industry sector, and will play an important role in the future. The final important parameter for predicting the energy consumption of the industry sector is the fuel mix, which includes different options for replacing the existing fuel technologies with new ones. Most of the bottom-up models that are used in assessing the long-term energy consumption of the industry sector focus on technology and energy efficiency. In [120] the authors focused on heat recovery and analysed its impact on the long-term energy demand in the French food industry. In the same paper the issue of using a top down and bottom up approach, in the industry sector modelling, was analysed. Given the previously mentioned arguments, the authors came to a conclusion that using a bottom up approach in the industry sector is the only option, especially if we want to quantify the impact of energy efficiency and new technologies on future energy consumption. Finally, the authors decided to use the commercial TIMES model to analyse the impact and possibilities of heat recovery in the French food industry. The authors in [121] analysed the capability of bottom up models to the adoption of energy efficient technologies. They gave guidelines and criteria for model comparison; explicit modelling of technology stock, financial costs, barriers and modelling policies.

In [122] the authors showed that the technology promotion is the main driver for energy saving in the iron and steel industry. The authors in [123] applied the TIMES model to forecast China's iron and steel industry consumption till 2050. In this case, the authors modelled this subsector through seven processes. Due to scarce input data the authors were limited to model only technical modifications and waste heat. The authors concluded that in the near future, reductions in energy intensity and CO_2 intensity will rely more on the energy efficiency improvements from the deployment of energy-saving technologies. However, from a long-term perspective, structural changes in steel production will be very important. In [124], the authors analysed four main methods for energy demand modelling of the industry sector; energy trend decomposition method, econometric models, top down models, bottom up models and industry specific macroeconomic methods.

1.2.7 Modelling limitations

Based on the literature review a strong sectoral approach can be detected, especially when it comes to detail and advanced engineering bottom-up models, with the lack of a comprehensive model that is able to model the energy consumption at the national level. One reason for this is certainly an exceptional level of details that the individual sectoral models require, which ultimately makes the national models too complex. Commercial bottom-up models are usually simplified, to be able to work with a simpler set of input data, focusing on macroeconomic parameters, giving the long-term assessment of energy consumption at the national level [125].

Bottom up approach has a main flaw in a form of large number of input data that is required when establishing a reference year of the calculation. This is very often combined with a lot of average figures or measured data which can considerably influence the final results [37][99].

1.2.8 Reference year

Before creating all sectoral models, detailed data collection and validation is necessary, especially energy balances and various statistics. This is followed by preparation of the mathematical model based on a given reference year [26]. Further elaboration of the reference year is necessary since in that case input and output data are known, which makes it possible to perform the calibration of all input parameters, verify the model itself or calculate certain parameters which are not available in the reference year. For this research, 2011 was chosen as the reference year. There are several reasons for this. The first one is the availability of the national energy balance during 2014, when this research was finalized. The second reason was the statistical info available for 2011, as the national census year. And finally, the third reason was the national report from Odyssee database available in 2012 with all economic sectors covered.

1.2.9 Future energy demand forecast

After creating and testing the model through reference year input data, the next step is the analysis of energy regulations (energy policy implementation). Prior to the implementation of energy legislation and financial mechanisms, creating a reference (baseline) scenario, which will serve as a benchmark, is necessary. The authors in [126] explained the formalized concept of reference year modelling. Modelling technological development within the model is based on the implementation of various technologies in the reference year, and their further modification in the process of modelling the long-term energy demand.

One of the key challenges in future energy demand planning is trying to decouple energy consumption and economic growth. With a bottom-up approach, such decoupling can be performed more easily, where the focus is on the end use. Predicting future energy demand more precisely and quantifying and describing all possible future energy savings leaves room for higher penetration by renewable energy sources (Figure 10) [85]. Today, long-term energy demand planning cannot be left to "trend analysis". Different energy policies and technologies will have a significant impact on future transport systems [127].

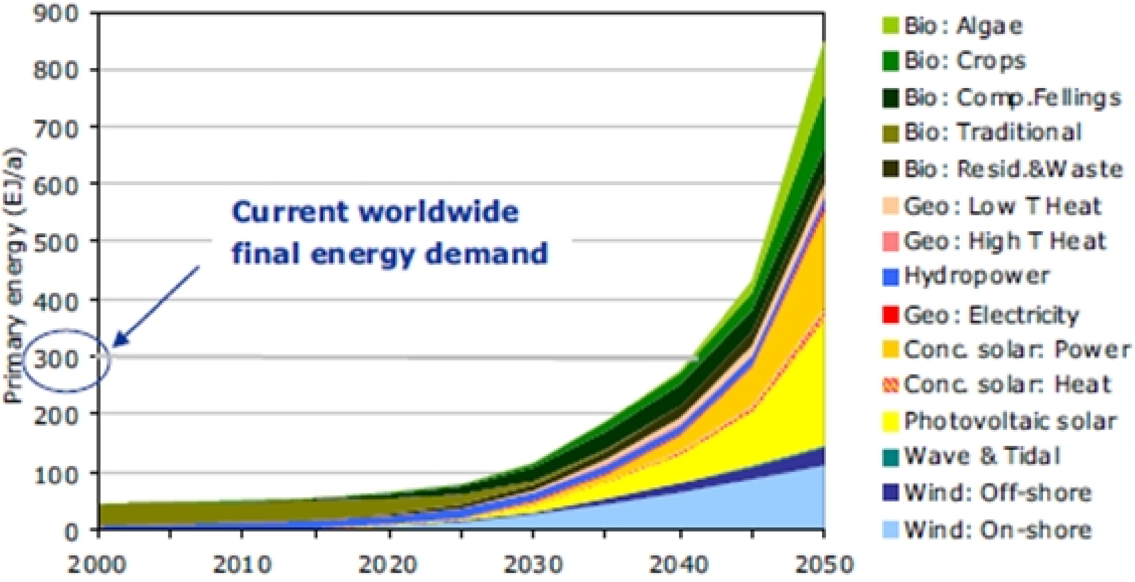


Figure 10 Renewable energy sources matching the energy demand[10]

The authors in [128] tried to quantify how specific assumptions influence the scenario outcomes. Opposite to what you might expect sensitivity analysis on availability and energy prices had a very small effect on the GHG emissions in the 2020 (less than 2%). On the other hand socioeconomic assumptions followed by technology development had a much higher impact on the GHG emissions.

1.2.10 Mechanisms influencing energy demand and their quantification

---

[10] Ecofys

The development of the NeD model, capable of analysing energy systems at the national level, was based on several phases. In the first phase the focus was on the development of separate models which analyse and model long-term energy demand on sectoral level. Six main economic sectors were chosen; industry, transport, households, services, agriculture and construction. This choice was based on national energy balance of the Republic of Croatia which will be used as a case study in this research. In the literature, different combinations are possible and applied. For instance, the agriculture sector is often classified under the industry while the construction sector is often put into the transport sector. This division allows better results validation and results comparison to possible future models and studies.

For the development of the households sector the HED model [37] was used. The same model was used for the purposes of the services sector modelling, with the exception of the tourism and catering trade subsector which was modelled based on [102]. Main mechanisms included the implementation of the EPBD (Energy Performance of Buildings Directive) [48] through strict dynamics of new built buildings and the refurbishment of the existing building stock. The model identifies the year 2020 as a key in the wider implementation of nearly zero energy buildings, which means that up to this year the model relies on the existing legal framework that applies to Croatia regarding the rational use of energy in buildings. Buildings in Croatia spend about 40% of final energy which makes their renovation a great potential. The refurbishment of any building in a given year in the future implies the same regulations and standards for the newly built buildings in the same year. The model is capable of the sensitivity analysis which shows how different yearly refurbishment rates of 1% to 3% affect the total final consumption, which is in line with the Directive on energy efficiency [129]. In [130], the authors developed a bottom up model for the assessment of the Irish energy efficiency action plan. As the best possible approach they have adopted the archetype approach.

For the implementation of the transport sector in the national model, the EDT model, described in the paper [26], was used. The model implements the EU regulations concerning the energy efficiency of internal combustion engines (g CO_2/km) and thus regulates the populations of vehicles with different energy efficiency, or energy consumption. The calculation is set up so that the new vehicles entering the system reach 130 g CO_2/km in 2015, while for 2021 this limit is set to 95 g CO_2/km. One of the potential measures was the analysis of the transport system with the complete electrification of the passenger cars segment in 2050 and a complete phase out of LPG (Liquefied Petroleum Gas) in 2030. It was also important to examine the result of the RES (Renewable energy sources) directive implementation, with special emphasis on the potential entry of biofuels in the transport sector. This Directive determines a share of 10% of renewable energy in the transport sector in 2020 [131].

For the analysis of the industry sector the IED model [119] was used, while for the other two sectors, agriculture and construction, new models were developed and implemented into the NeD model. As the last major part of the national model, the implementation of the module that is capable of calculating greenhouse gas emissions was necessary. This module includes all of the above sectoral models and uses their results to calculate greenhouse gas emissions at the national level. The calculation of greenhouse gas emissions is based on the IPCC (Intergovernmental Panel on Climate Change) methodology, whose conversion factors were implemented in the model as input data.

1.3 Novelty of the research

The idea of this research is to find a new method which will, by combining several approaches used in the energy planning, lead to a new and better mathematical model capable of quantifying the influence of energy policy on long term energy demand. This new model will take into account all technological aspects as well as legal and financial mechanisms influencing future energy demand. The model will be applied and tested with Croatia as a case study, but it would also be applicable to other systems globally.

1.4 Hypothesis

The objective of research is to develop an advanced method and a mathematical model for final energy demand planning, by taking into consideration various energy policies. The method will be based and tested through sectoral analysis at the national level, where the focus will be on showing which mechanisms of energy policy allow the biggest energy savings and minimum environmental impact. The research work will prove the hypothesis that the advanced energy planning, based on bottom up engineering approach, and taking into consideration all aspects of energy policy, can identify measures that will lead to significant energy savings in Croatia till 2050, lower final energy demand, lower environmental impact and decrease national dependence on foreign fuel imports.

1.5 Structure of the thesis

As a part of this research, improved methodology for long term energy demand planning on a national level has been created and presented. Most of that methodology has already been published in peer review journals:

- Households [37]
- Transport [26]
- Industry [119]
- Tourism [102]
- Agriculture, Construction and Greenhouse gas emissions mode [132]

As a result of this research, the National Energy Demand model was created (NeD Model). The model was built in MS Excel, while possible upgrades were considered by using some of the Visual Studio applications. This provides a wider compatibility, primarily in the processing and implementation of the data obtained in previous stages. It also opens the possibility of a simple upgrade of the model and later adjustment for other possible national energy systems.

The final result of the thesis is a finalized package or model, which is capable to create scenarios and analysis of final energy consumption for any energy system, including sub-sectors. As the final step in the thesis preparation, testing the developed model, with Croatia as a case study, was done. When testing the model, the influence of energy policy on future energy demand was shown as well as the influence of technology development.

In order to compare the results obtained from the developed models, the author used a commercial model for energy demand planning LEAP (Long Range Energy Alternatives

Planning System). Comparison of the results was done within the limitations of the LEAP model.

Finally, for every sector, the influence of main energy policy measures on the whole national final energy demand will be presented via energy wedges. Energy wedge represents one energy policy measure. By combining and adding more energy wedges on the total national final energy demand the author will show the possibilities of achieving ambitious EU energy and GHG emission goals in Croatia. Energy wedges methodology comes from the characterization of GHG emissions based on the so called wedge concept[11], introduced by Princeton researchers. The principle is to establish business as usual scenario and afterwards various wedges are applied to stabilize or additionally reduce GHG emissions.

---

[11] http://cmi.princeton.edu/wedges/

2 METHODOLOGY

2.1 Developing a national scale energy demand model

In order to analyse final energy demand of a country and construct its long-term energy demand projection, the NeD model was constructed. The model was comprised out of six modes, each representing one economic sector: households, industry, transport, services, agriculture and construction (Figure 11). The development of the model was done through stages, with a detailed long-term energy demand model, of one economic sector, presented in each stage. Since every previously developed model was constructed in MS Excel tool, their synthesis was relatively easy. The final stage in the construction of the NeD model was the creation of a GHG emission module that would unify and cover all six sectors.

Since one of the main intentions of the NeD model was to decouple economic growth from the energy consumption and focus on different energy policies as main driving parameters influencing future energy demand, very detailed engineering model based on the end-use categories was the only valid approach. The NeD model presents a valuable tool which can be used for the integral energy planning process.

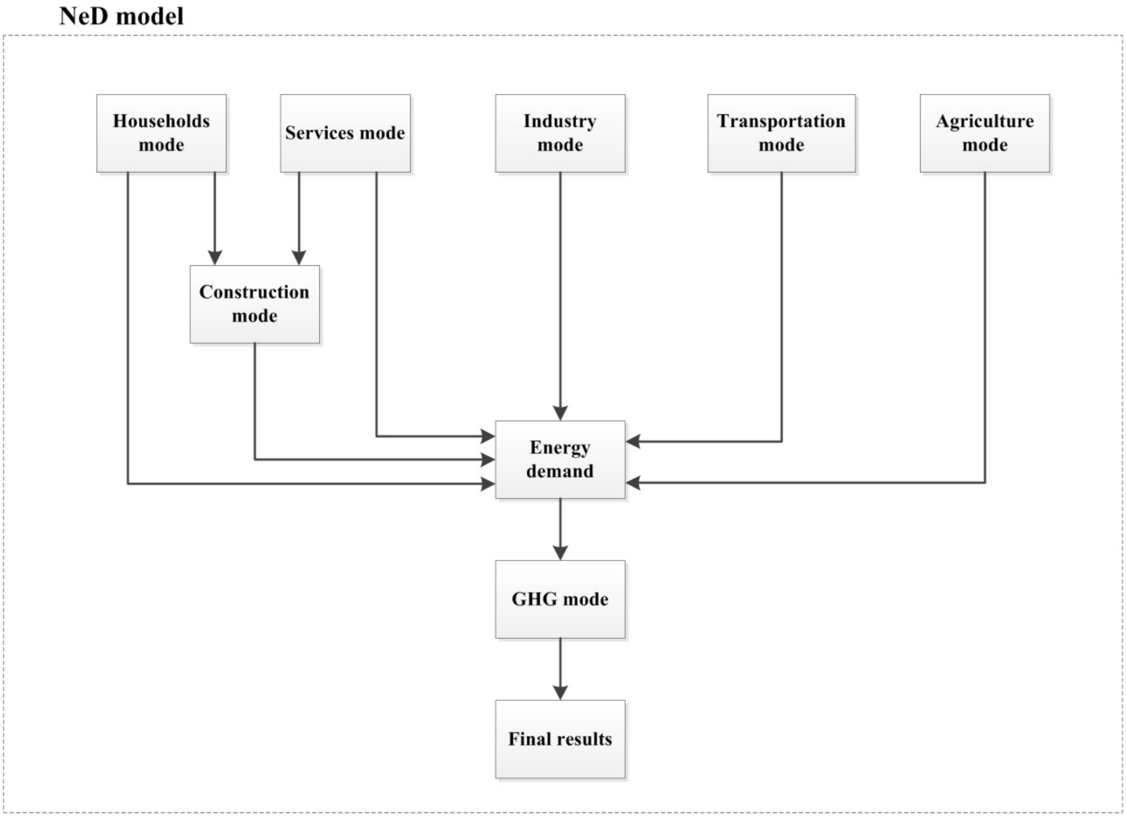


Figure 11 NeD model overview

Projecting future energy demand is a starting point for any future advanced system analysis where energy demand data presents a key input parameter [51]. The NeD model can support supply side oriented energy planning models and tools in more accurate energy system analyses [133] [134].

For the purposes of this research other long-term energy demand models were analysed and tested. The main intention was to analyse their advantages and disadvantages. The two most interesting ones, regarding energy demand planning, were LEAP (Long range Energy Alternatives Planning) and MAED-D (Model for Analysis of Energy Demand). LEAP presented a good accounting energy demand/supply model with the advantage of being easy to use and the input data not too extensive [135] [136]. In [137] the authors used LEAP to develop GHG mitigation scenarios for Brazil. The authors analysed various measures from both demand and supply side. At the same time, LEAP did not present the level of details if compared to the NeD model which, for instance, has the ability to model heat/cooling demand of households and services sectors on an hourly level for any year until 2050. This was especially important because the main intention of the NeD model was to use its results as input data for supply side models.

Of course, there are other similar models used for the same time periods. In some cases the TIMES model is used for very long time periods, e.g. till 2100, in order to assess the least costly energy path. The authors in [138] forecasted energy demand, fuel mix that meets that demand and associated emissions. Of course, the uncertainties for such periods, especially from a socioeconomic perspective, are very difficult [138]. But these very long time periods are not in the scope of this research.

The main disadvantage of accounting models, including the NeD model, was their inability to perform any type of optimization that could result in the least costly solution. Second bottom up energy demand model tested, was MAED-D. Here the model was less user friendly and required detailed and specific input data which could be difficult to obtain [139] [140]. The additional disadvantage of MAED-D was its inability to modify the model structure which could be very interesting and useful in some cases. The advantage of the MAED model was the fact that it was a well structured and organized model, which allowed an easy start of the modelling process. The MAED model can be considered as a starting point of the NeD modelling methodology. Another advantage of the MAED model was its MAED-el part, which allowed partial downgrade of yearly electricity consumption to an hourly level.

However, the NeD model presents a significant upgrade and improvement in comparison to the MAED model, especially in the terms of useful energy demand calculations of the households and services sectors.

One of the biggest advantages of the NeD model was its ability to model various energy policy scenarios through endogenous parameters. This allowed more accurate calculations when energy demand projections were made. In the following paragraphs, main equations and logics of the NeD model will be presented as well as the final part of the NeD model, which was the GHG emission module.

2.1.1 Households sector

The NeD households sector was constructed by importing and adopting the HED (Households Energy Demand model) methodology, previously developed for the Croatian households sector [37]. The main logics in calculating future energy demand are presented in Figure 12. To calculate space heating and cooling demands, as well as the energy needed for cooking, hot water and electric appliances, population and available floor surfaces needed to be calculated first. When calculating available floor surfaces, all floor surfaces that would have been renovated, newly built and demolished in every year until 2050 were calculated. Available floor surfaces were calculated on the NUTS 3[12] level. After the available floor surfaces, outer envelope surfaces were calculated and the basic thermodynamic equations for useful space heating/cooling demand were set. Thermodynamic calculations were based on quantifying transmission and ventilation losses on one side and internal and solar gains on the other. All demands, except electric appliances, were first calculated at the useful energy level. Afterwards, in the fuel mix mode useful energy was transferred to a final energy level, combining different technologies and market shares.

The HED Model is based on summarizing different sub-categories of households sector in order to get an overview of its energy consumption. By segregating the entire sector, deeper insight of an each sub-category can be obtained in order to see the differences in future energy consumption, which are dependent on various factors and mechanisms. The HED Model is made for long term energy demand projections, in this research till 2050, and is focused on presenting the final energy demand of the households sector. Various sub-categories (modes) are introduced in order to describe all the specificity of energy consumption of the households sector: space heating, electric appliances including space cooling, hot water and cooking. Basic overview of all main modes and their interaction is presented in Figure 12. Detailed description of all sub-categories, or modes, and their specific properties will be presented in the following paragraphs.

---

[12] Nomenclature of Territorial Units for Statistics

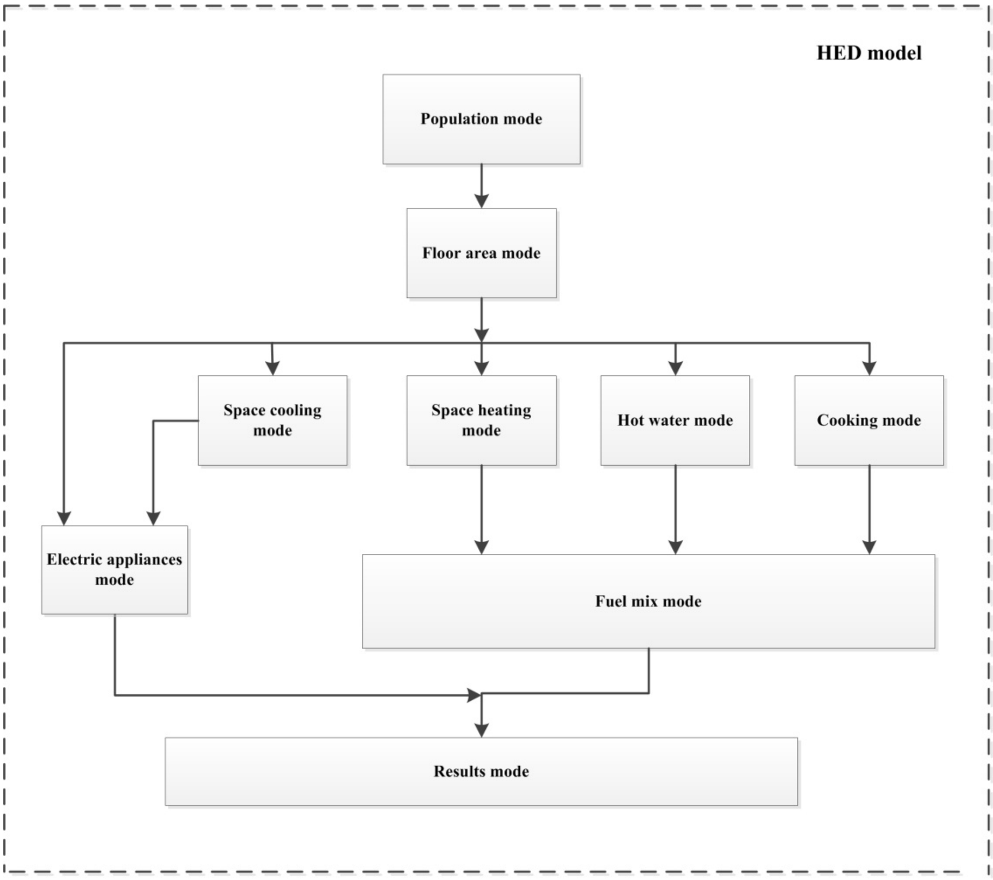


Figure 12 Overview of the households energy demand calculation

2.1.1.1 Available floor area and population

In order to start modelling the actual energy consumption and demand, first a detailed mode that would predict the fluctuation of available floor area of the households sector had to be developed. Modelling future available floor area of the households sector is made by using available future population information available from the Bureau of Statistics (DZS)[13]. Population mode is structured in order to describe possible migration trends. These trends are usually with a clear migration to major cities and the nation's capitals. This geographical population shift could lead to a significant difference in energy demands. Every user can modify the HED model and set the parameters of migration. The first possibility is to presume constant geographic ratio regarding population and the second one is to model specific migration trends for every future year. Population information and future fluctuation till 2050,

---

[13] Državni zavod za statistiku - www.dzs.hr

on an aggregated national scale, are taken from national bureaus of statistics so they are not modelled but just imported as input data into the HED model.

As seen in Figure 1 available floor area and their future fluctuation is one of the key parameters of the HED model. It presents an input for the rest of the energy related modes. The model also has the ability to take into consideration various building types and calculate future available floor area trends. The main categories include: permanently occupied dwellings and partially occupied dwellings. This methodology could be further divided, depending on the available input data. As a backup solution, in the case of limited input data, the model has the possibility of working with the total available floor area of every county which is then modified in the following modes by the occupancy indexes. This is done by modelling a reference year, which is chosen by the user. This step allows for all the input data to be tested and verified. Available future floor area fluctuations are calculated on the NUTS 3 level, with population data and specific available floor area as main parameters:

$$A_i^z = P_i^z \cdot M_i^z \tag{1}$$

Where: A_i - total available floor area in a certain county [m^2], P_i- population of a certain county, M_i- specific available floor area of a certain county [m^2/person], z - year for which the calculation is made

The model calculates new available floor area in the system and summarizes it in order to have precise information regarding floor area distribution for the heating and cooling energy consumption calculation. The same principle is applied for renovated buildings, with an exception of the renovation paste index which is set by the user. The model calculates demolished floor area for each year through historic index, which can be imported into the model by the user.

$$N_i^z = A_i^z - A_i^{z-1} + D_i^z \tag{2}$$

Where: N_i - new available floor area in a certain county [m^2], D_i - demolished floor area in a certain county [m^2]

$$R_i^{\,z} = A_i^{\,z-1} \cdot S \qquad (3)$$

Where: R_i - renovated available floor area in a certain county [m^2], S - renovation paste index

$$tR_i^{\,z} = tR_i^{\,z-1} + R_i^{\,z}$$

Where: tR_i - total renovated building stock [m^2]

$$tN_i^{\,z} = tN_i^{\,z-1} + N_i^{\,z}$$

Where: tN_i - total new building stock [m^2]

$$Bs_i^{\,z} = A_i^{\,z} - tN_i^{\,z} - tR_i^{\,z}$$

Where: Bs_i - “old” building stock [m^2]

Floor area that is renovated or newly built is calculated on a yearly basis, for a specific year (N_i and R_i). However, the HED model tracks and calculates total floor area which is newly built or renovated in every county for every specific year (tN_i and tR_i). The same principle applies to the total number regarding floor area for every county that is still not being renovated. The final outcome of the Floor area mode is a detailed overview and information on available floor area of all building categories for every geographic unit. The model calculates specific available floor area based on all of the imported data referring to the reference year. Afterwards the user can set a paste of specific available floor area fluctuation for every geographic unit. This way the user can describe current trends of increasing the living area per resident.

2.1.1.2 Space heating and cooling

Calculating heat demand has proven to be a challenging task because of adjustments and all specific characteristics in calculating the thermodynamic behaviour of an outside envelope, applied to an entire sector. That is why the HED model calculates energy consumption for the reference year in order to test the methodology and all input parameters and factors. For the purposes of this research, reference year is set to 2011. Testing the methodology on a reference year is convenient since energy consumption, in this case output data, is already known. This is also a way to calculate and verify all unknown parameters which are later on used in the model for the calculation of future energy demand.

2.1.1.2.1 Heat demand

Heat demand is determined based on the previously calculated available floor area distribution among all counties which is combined with climatic information characteristic to a specific county. Base calculation of heat demand is made by deducting heat gains from heat losses. Heat losses are determined as heat transfer by transmission and ventilation while heat gains are determined as solar heat gains and internal heat gains.

$$Q_i^z = (Qt_i^z + Qv_i^z) - (Qs_i^z + Qi_i^z) \qquad (4)$$

Where: Q_i - total heat demand [PJ], Qt_i - heat transfer due to transmission [PJ], Qv_i - heat transfer due to ventilation [PJ], Qs_i - solar heat gains [PJ], Qi_i - internal heat gains [PJ]

Calculation is based on a monthly procedure which roughly follows the ISO 13790 [141] norm for energy performance of buildings. Heat transfer due to transmission is based on outside envelope surfaces which are calculated based on available floor area, thermal transmittance and temperature differences. Every geographic unit is given a reference climatic constrains that are used to calculate transmission losses.

$$Qt_i^{\ z} = (h^z \cdot v \cdot Ae_i^{\ z} \cdot vU_i^{\ z} \cdot \Delta T_i^{\ z} \cdot t) + (h^z \cdot w \cdot Ae_i^{\ z} \cdot wU_i^{\ z} \cdot \Delta T_i^{\ z} \cdot t) \qquad (5)$$

Where: h - share of floor area heated [%], v - wall percentage of available envelope surface [%], Ae_i - available envelope surface [m^2], w - window percentage of available envelope surface [%], vU_i - thermal transmittance of walls [kW/m^{2}K], wU_i - thermal transmittance of windows [kW/m^{2}K], ΔT_i - temperature difference between outside monthly average temperature and inside temperature [K], t - duration of calculation step [h]

When calculating available envelope surface, the user can define the ratio between windows and walls as well as future improvements regarding the envelope. Future improvements are set through different thermal transmittance factors of walls and windows for every year of the calculation. This way all energy efficiency initiatives are describable and quantifiable for every year. Temperature difference for every county is based on real climate data which are imported into the model. Heat transfer due to ventilation is calculated primarily based on an air exchange rate which is subject to modification by the user. The HED model calculates exchanged airflow based on available floor area, percentage of heated floor area, average height of heated floor area and air exchange rate.

$$q^z = h \cdot A_i^{\ z} \cdot he \cdot n_{ex}$$

Where: he - average height of heated floor area [m], n_{ex} - air exchange rate [s^{-1}]

$$Qv_i^{\ z} = \rho \cdot cp \cdot q^z \cdot \Delta T_i^{\ z} \cdot t \qquad (6)$$

Where: ρ - air density [kg/m^3], cp - air heat capacity [J/kgK], q^z - airflow [m^3/s]

Internal heat gains are calculated roughly following the ISO 13790 norm [141] which regulates internal heat gains per square meter of residential space while solar heat gains are based on window surfaces and solar irradiance which is a subject of geographical location.

$$Qs_i^z = c^z \cdot Aw_i^z \cdot g \cdot af_i \cdot ps_i \cdot I_i \cdot t \qquad (7)$$

Where: Aw_i - effecting collecting area [m^2], g - solar energy transmittance of transparent element, af_i - frame reduction factor, ps_i - shading reduction factor, I_i - solar irradiance [kW/m^2]

2.1.1.2.2 Cooling demand

Cooling demand is calculated based on cooling degree days since this method turned out to be the most appropriate for calculating the whole households sector. This methodology was used because the methodology used for heating demand, which was tested through the reference year consumption, did not produce satisfying results when applied to cooling.

$$Qc_i^z = (c^z \cdot v \cdot Ae_i^z \cdot vU_i^z \cdot Dd_i^z) + (c^z \cdot w \cdot Ae_i^z \cdot wU_i^z \cdot Dd_i^z) \qquad (8)$$

Where: Qc_i - total cooling demand [PJ], c - share of floor area cooled, Dd_i - cooling degree days

As well as in calculating heat demand, the user can set the ratio between windows and walls as well as set the thermal transmittance of both windows and walls for future period as a result of envelope improvements. The share of the cooled floor area can be modified for every year, allowing the user to describe the possible energy consumption increase in air conditioning, which is an important issue in countries with different climate zones.

2.1.1.3 Electronic appliances

Electronic appliances are observed from the point of electricity consumption and are divided into: large appliances, small appliances and lighting. This type of division is made based on various databases [142] in order to follow the existing methodology and compare consumption results and data. Based on this methodology, air-conditioning is a part of the large appliances category and its electricity consumption is calculated separately in order to use the data retrieved through the Cooling demand mode. In this case reference year calculations are essential in determining starting input data and calibrating it with the available literature information. In order to present total electricity used in the households sector, the electricity used for space heating, cooking and hot water is added to the electricity used by electronic appliances in the final Results mode (Figure 12).

The HED model can calculate energy consumption and future energy demand both through the available floor area as well as population information. For the purposes of this research floor area calculation is used. The first step of this calculation includes determining the starting values that are verified through the input data of a chosen reference year. Afterwards the user can set the energy efficiency improvements regarding specific consumption for the future period.

$$E_i^{\,z} = sp_i^{\,z} \cdot l_i^{\,z} \cdot A_i^{\,z} \qquad (9)$$

Where: E_i - final energy consumption of a certain electric appliances category [PJ], sp_i - specific consumption of a certain electric appliances category [kWh/m^2], l_i - energy efficiency improvements index in a certain year

Since cooling demand is previously determined through the Cooling demand mode, final energy consumption for space cooling is calculated through the coefficient of performance index. Electricity is presumed as a single “fuel” used to satisfy cooling demand. Further research on additional fuel forms that could satisfy cooling demand is expected in the following HED model versions. Coefficient of performance is set by the user as well as its potential future improvements. This way the user can calculate how future technology improvement would influence final energy demand for space cooling.

$$Ea_i^z = Qc_i^z / COP_i^z \tag{10}$$

Where: Ea_i - final energy consumption for space cooling [PJ], COP_i - coefficient of performance index

2.1.1.4 Cooking and hot water

The hot water demand is calculated roughly following the EN 15316-3-1 [143] norm that gives the calculation process for calculating energy demand for hot water in households. The norm states specific consumption per square meter which is incorporated into the model as an input data. Since there are discrepancies between an individual household and the whole households sector, specific consumption is calculated based on imported data, available floor area and real final energy demand established in the reference year. This is how the difference between the sectoral and individual approach to the norm could be compensated.

The hot water mode calculates only energy demand based on the input data while final energy demand, based on different technologies and their efficiencies, is determined in the Fuel mix mode. Fuel mixing is described in a more detailed way in the following paragraph 2.5.

Final energy demand for cooking is calculated directly within the Cooking mode, based on the same methodology used for hot water consumption. The difference in this case is that the cooking demand enters the Fuel mix mode as the final energy demand. Because of that, the Fuel mix mode is used only to determine various fuel types without calculating changes in energy efficiency. When modelling the cooking demand, a combination between empirical data retrieved through polls and reference year consumption was used, but just to test and verify the poll data.

2.1.1.5 Fuel mix

The HED model has a separate Fuel mix mode, which combines energy efficiency of each technology and share ratio of each fuel type in the final energy demand, for every sub-category. This mode is necessary for calculating final energy demand for heating, hot water and cooking. Through this mode the user can combine various technologies and fuel types in a scenario approach, in order to compare different strategies regarding future energy demand planning. Initial energy mixes are calculated based on the input data for the reference year. The user can set the paste of efficiency and fuel ratio change for every year till the year 2050. With efficiency and fuel ratio for every technology and fuel type, final energy demand for the three previously mentioned sub-categories is calculated. The Results mode is used in order to present final energy demand for electricity. In this mode electricity used for space heating, cooking and hot water is added to electricity used by electronic appliances.

$$F_i^z = \sum_{i=1}^{n} fd_i^z \cdot ee_i^z \cdot r_i^z \qquad (11)$$

Where: F_i - final energy demand [PJ], fd_i - energy demand [PJ], ee_i - energy efficiency index, r_i - share ratio of a certain fuel type index

Presented methodology is used for calculating final energy demand for heating, hot water and cooking. Table 1 presents fuel mix used for calculating a reference year fuel ratio. District heating was chosen to represent steam and hot water which are used in the official Croatian energy balance when describing final energy demand of the households sector. Additional fuels can be added to the model as well as additional technologies.

Table 1 Fuel mix used in version 1 of the HED model

Mode	Fuel mix
Heating	Coal & Coke
	Natural gas
	Liquid fuel
	Electricity – resistance heating
	Electricity – heat pumps
	Biomass
	District heating
Hot water	District heating
	Natural gas
	Electricity
	Solar water heating
Cooking	Natural gas
	Liquefied petroleum gas
	Electricity

2.1.1.6 Hourly demand calculation

One of the additional features of the HED model is the possibility of calculating hourly distributions of heat and cooling demand. Hourly calculation is used just as a control of the results retrieved from already presented monthly calculation. The calculation procedure is the same as the one presented in paragraph 2.1.1.2.1, with the exception of temperature and solar irradiation data. In the hourly calculation these two parameters are imported into the model as hourly values. This means that every county is represented with 8760 temperature and solar irradiation values. The main intention of hourly demand projections is making the HED model compatible with advanced energy system analysis tools which use hourly demand distribution as their input data [51][144]. With the HED model the user can export hourly heat and cooling demand distributions for any year till 2050. Although the focus of this research is on total yearly final energy demand, hourly heat demand will be presented in the results section.

2.1.2 Transport sector

The NeD transport sector was constructed by importing and adopting the EDT (Energy Demand in Transport model) methodology developed previously for the Croatian transport sector [26]. The methodology was based on the principle of covering and analysing every subsector (road, rail, sea and river, air and public transport) separately and then summing their contributions in the final energy demand balance. Every subsector was specific in the energy demand calculation procedure, but one unified note could be identified. Calculations were based on modelling the dynamics of the end-users until 2050 (vehicles, trains, buses, aircrafts, ships, trams, etc.), their efficiency, usage, availability, etc. This dynamic was based on calculating yearly values for all end-use categories entering and exiting the system.

For personal vehicles, the number of personal vehicles entering the system was calculated based on two levels. First, the number of alternative personal vehicles entering the system (electric and hybrid vehicles) was calculated. Based on their dynamics, the number of other personal vehicles that run on conventional fuels (gasoline, diesel and liquefied petroleum gas) entering the system was calculated. Thus, for every alternative vehicle entering the system, a certain percentage of conventional vehicles was reduced. The numbers of electric and hybrid vehicles entering the system were calculated based on market penetration S curves. First, all statistical data needed to be imported into the model to start the necessary calculations. Afterwards, based on the reference year, all missing and unavailable parameters could be calculated and tested, which was the main condition before starting to predict future energy demand. Different scenarios, that could show and quantify how different energy policies influence future energy demand, could be set.

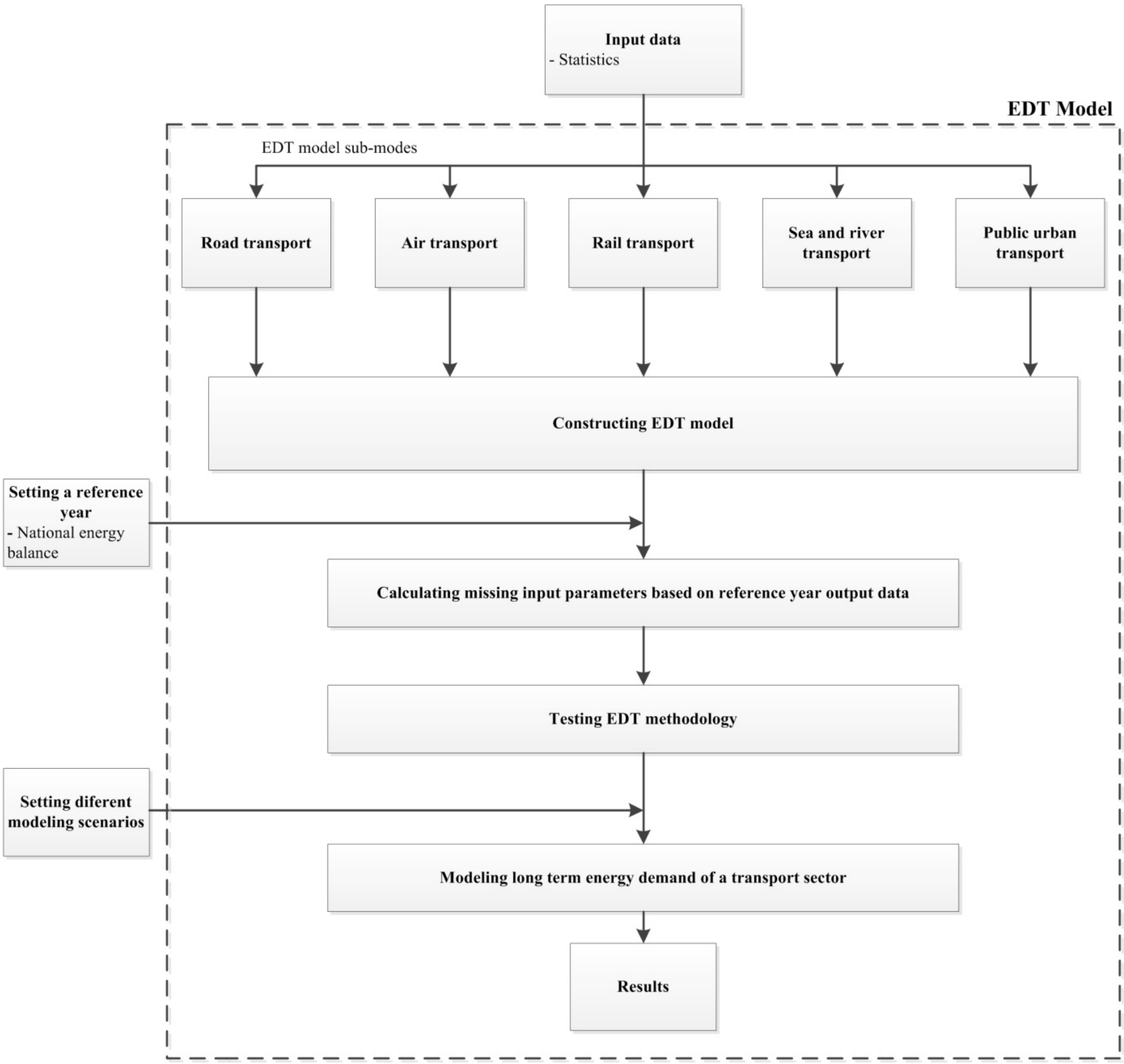


Figure 13 Overview of the energy demand planning methodology of the transport sector

A cross-subsector connection only occurred when calculating the modal split among road, air and rail transport. The energy value of each tonne kilometre and passenger kilometre until

2050 was calculated. After that the modal split dynamics were set, and the tonne kilometres and passenger kilometres were transferred from one subsector to another. General overview of the methodology and calculation procedure is shown in Figure 13.

2.1.2.1 Road transport

In most countries, the majority of the final energy demand is due to road transport. Thus, modelling road transport and its future energy demand is the most important goal of the EDT model. Accordingly, this part of the model is also the most detailed one in terms of methodology. Road transport is modelled based on the number of vehicles exiting and entering the system, their efficiency, usage, technology and fuel consumption. Vehicles include motorcycles, personal vehicles, buses, trucks weighing less than 3.5 tonnes and trucks weighing more than 3.5 tonnes. The National Bureau of Statistics was used as the starting point to unify all input data and make the results comparable to any future study. Summing the consumption of all categories yields the total final energy demand of the road transport subsector. The EDT model can model energy efficiency improvements, technology switching and fuel switching. The technologies currently available in the model are vehicles with internal combustion engines, electric vehicles and hybrid vehicles.

Regarding fuel types, the EDT model works for gasoline, diesel, liquefied petroleum gas, compressed natural gas, electricity, biofuels as well as synthetic fuels. The final annual energy demand of each category in road transport is calculated based on the following formula, where *i* represents the vehicle type:

$$trD_i^z = \sum_{i=1}^{n} \left(trE_i^z \cdot trM_i^z \cdot Cv_i \cdot P_i^z \cdot Cm_i \cdot trQ_i \right) / 10^{11} \tag{12}$$

Where: trD_i - energy demand of a certain category of road transport [PJ], trE_i - number of vehicles of a certain category of road transport, trM_i - fuel consumption of vehicles of a certain category of road transport [l/100 km], Cv_i - fuel consumption energy efficiency index, P_i - usage of vehicles of a certain road transport category [km/year], Cm_i - usage efficiency index, trQ_i - heating value of a fuel type that a vehicle is using [MJ/l]

The total number of each type of vehicle is calculated based on the existing vehicles in the system and the vehicles that are entering and exiting the system continuously every year:

$$trE_i^{\,z} = trE_i^{\,z-1} + trN_i^{\,z} - Cf_i^{\,z} \tag{13}$$

Where: trN_i - vehicles entering the system, Cf_i - vehicles exiting the system

Technology as well as fuel switching is modelled by considering all of the vehicles entering the system. Different scenarios depending on various fuel mixtures can be calculated by the EDT model. In this case, the most interesting vehicles are personal vehicles, for which the greatest extent of technology switching in the forthcoming years can be expected. The number of personal vehicles entering the system is calculated based on two approaches. First, the number of alternative personal vehicles entering the system (electric and hybrid vehicles) is calculated. Based on their dynamics, the number of other personal vehicles that run on conventional fuels (gasoline, diesel and liquefied petroleum gas) entering the system is calculated. Thus, for every alternative vehicle entering the system, a certain percentage of conventional vehicles is reduced. The numbers of electric and hybrid vehicles entering the system are calculated based on market penetration S curves, which can be described by

$$f(x) = \frac{x}{\sqrt{1+x^2}} \tag{14}$$

The value of x in equation 14 is arbitrary and is determined by the user to construct the most appropriate S curve. The value of x is assigned for every year, from the reference year to 2050. Based on the constructed S curve, the final number of a certain type of vehicle entering the system in 2050, still needs to be set by the user. The final number of a certain type of vehicle entering the system each year, based on the constructed S curve and two boundary conditions: the number of vehicles entering the system in the reference year and that in the year 2050, is then assigned by the model. The dynamics of market penetration for every alternative vehicle category are determined by the shape of an S curve. As every long term plan an S penetration curve has to be occasionally modified to follow the real market conditions.

The number of conventional-fuel personal vehicles entering the system is determined by the total number of personal vehicles entering the system, which is determined by the user, and the number of alternative personal vehicles. After the total number of vehicles entering the system in the year 2050 is set, the data are linearly extrapolated from the reference year. This extrapolation is performed by determining the increase or decrease in specific car ownership (car/capita). In the EDT model, all demographic data are imported from national bureaus of statistics. Finally, the number of conventional-fuel personal vehicles entering the system is calculated as follows:

$$N_i c^z = (n_i^{\;z} - \Sigma N_i a^z) * Cn \tag{15}$$

Where: $N_i c$ - conventional personal vehicles entering the system, n_i - total number of personal vehicles entering the system, Cn - share of a certain type of conventional personal vehicle in the total number of personal vehicles entering the system every year, $N_i a$ - alternative personal vehicles entering the system

Using market penetration S curves provides the best possibility of phasing out certain conventional-fuel technologies and the most probable dynamics of alternative personal vehicles entering the transport system. The x coefficients in equation 14 can be set to have the most suitable dynamics for market penetration. In the results section, examples of this interaction between alternative and conventional-fuel personal vehicles are provided.

2.1.2.2 Rail transport

In terms of energy, rail transport is divided into two forms of fuel sources, electrical energy and diesel fuel. In this case, their interaction is a major part of modelling the energy demand in this subsector. The final energy demand is calculated as the sum of the consumptions of the two fuel types.

$$trR^z = \sum_{i=1}^{n} e_i^{\,z} \tag{16}$$

Where: trR - energy demand of rail transport [PJ], e_i - energy consumption of a certain fuel type [PJ]

Each fuel type group is calculated based on the number of vehicles (locomotives, trains or pulling carts) and their consumption and efficiency.

$$e_i^{\,z} = \sum_{i=1}^{n} \left(m_i^{\,z} \cdot a_i^{\,z} \cdot b_i^{\,z} \cdot trq_i \right) / 10^6 \tag{17}$$

Where: m_i - number of a certain vehicle type, a_i - average yearly consumption of a certain vehicle type [t/year], b_i - energy efficiency index of a certain vehicle type, trq_i - heating value of fuel used by a certain vehicle [MJ/kg]

The total number of each type of rail vehicle is calculated based on the current number and the possibilities of new vehicles entering and old vehicles exiting the system.

For rail vehicles using diesel fuel:

$$m_i d^z = m_i d^{z-1} - mn_i^{\,z} \tag{18}$$

For vehicles using electrical energy:

$$m_i e^z = m_i e^{z-1} + cs \cdot mn_i^{\,z} + mm_i^{\,z} \tag{19}$$

Where: $m_i d$ - number of diesel vehicles in the system, mn_i - number of diesel vehicles exiting the system, $m_i e$ - number of electrical vehicles in the system, mm_i - new electrical vehicles entering the system, cs - technology switch index

The number of rail vehicles entering the system is calculated based on future projections regarding new tracks that are going to be built, switching from one-track railways to double-track railways and switching from non-electrified tracks to electrified tracks. The equation that calculates the number of new rail vehicles entering the system and technological switching between diesel vehicles and electrical vehicles is a function of these three mentioned parameters.

2.1.2.3 Air transport

The fuel types used for air transport are reduced to only kerosene in this model; although synthetic fuel can also be substituted for kerosene. To specify and divide air transport in a more detailed way, the EDT model uses three types of aircraft to determine the total energy demand of the whole subsector: turboprop, single-aisle and wide-body aircraft. Energy consumption is calculated based on the usage, consumption and energy efficiency of all three types of aircraft.

$$Air^z = \sum_{i=1}^{n} (k_i^z \cdot cn_i \cdot qk_i^z)/10^9 \tag{20}$$

Where: Air- energy demand of air transport [PJ], k_i - kilometres flown [km], cn_i - yearly fuel consumption [kg/km], qk_i - heating value of fuel [MJ/kg]

When calculating values regarding mileage and time spent in usage per day, the model operates with physically maximum possible values, although boundary conditions can be set based on the current or future expected situation.

$$k_i^z = trl_i^z \cdot p_i \tag{21}$$

Where: trl_i - yearly kilometres flown of a certain aircraft type [km], p_i - number of aircrafts

The EDT model leaves space for both input data as well as all boundary conditions to be modified, making it applicable to other transport systems.

2.1.2.4 Sea and river transport

When looking at energy balances in this subsector, which have a strong international component, bunker fuel is discarded from the energy point of view. The EDT model calculates energy consumption in all inland river transport and coastal sea transport.

$$Sea^z = Sr^z + Ss^z \tag{22}$$

Where: Sea - energy demand of sea and river transport subsector [PJ], Sr - energy consumption of river transport [PJ], Ss - energy consumption of costal sea transport [PJ]

The primary fuels consumed in this subsector are diesel and heavy fuel oil. This version of the EDT model has the capability for fuel switching with the introduction of biofuels. The calculation of fuel consumption in the reference year and future energy demand is made based on two methodologies, depending on the available data. River transport is calculated based on actual power (kW) and specific consumption, while coastal transport is calculated based on actual number of vessels and their specific consumption.

$$riv^z = trp^z \cdot pp^z \cdot Cp^z \tag{23}$$

$$s^z = B^z \cdot bb^z \cdot Cj^z \tag{24}$$

Where: riv - river transport fuel consumption [t/year], trp - available power [kW], pp - specific consumption [t/kW], Cp - river transport fuel consumption energy efficiency index, s - costal transport fuel consumption [t/year], B - number of vessels, bb - specific consumption of a vessel [t/year], Cj - coastal transport fuel consumption energy efficiency index

The EDT model calculates the number of future vessels as a function of total passenger seats, average passenger seats per vessel, total passengers carried and average occupancy.

2.1.2.5 Public urban transport

The public transport subsector is composed of vehicles that run on electricity, diesel, biodiesel and CNG (compressed natural gas). It is important to note that in this classification, suburban electrified rail transport is excluded and included in the rail transport model. Public urban transport energy consumption and future demand are calculated by summing the consumptions of all previously mentioned fuels. When calculating energy consumption, the main parameters are vehicle usage, consumption and energy efficiency. Again, the model has the capability of introducing boundary conditions such as the possible daily kilometres that a certain vehicle can run or the energy efficiency index determining minimum and maximum fuel consumption.

$$U_i^z = u_i^z \cdot fe_i \cdot t_i^z \tag{25}$$

Where: U_i - consumption of a certain type of fuel [tonne, kWh], u_i - consumption of a certain type of vehicle [tonne, kWh], fe - energy efficiency index of a certain vehicle type, t_i - number of vehicles

Technology switching in the public urban transport is modelled among different fuel types, with a special emphasis on replacing diesel fuel with biofuels and compressed natural gas, at least in the short run. Fuel consumption is directly related to the fleet condition and is a function of different fuel mixtures.

2.1.2.6 Modal split among subsectors

Modal split among subsectors in the EDT model is calculated through passenger kilometres and tonne kilometres. Based on historical information or user inputs, the energy value of a passenger or tonne kilometre is calculated by the model for every subsector. Afterwards, the number of passengers or tonne kilometres is calculated for every year based on the previously calculated energy consumption of every subsector, making it possible to set up different scenarios. Modal split is best calculated if major infrastructural works can be foreseen, such as building high-speed rail in certain parts of the country. If such information is not available, these plans can be simply defined using a scenario approach for future scientific research. In the results section, the possible energy savings due to the modal split between road, air and rail transport are presented and analysed.

2.1.3 Industry sector

The NeD industry sector was constructed by importing and adopting the IED (Industry Energy Demand model) methodology previously developed for the Croatian industry sector [119]. There were four major parameters, when it came to energy demand projections, covered through this methodology. Special focus was given to export/import component, which determined the ratio of domestic production capacities, resulting with changes in energy demand.

First, consumption per capita has been integrated in the IED model with the purpose to incorporate the influence of population on product consumption. Consumption per capita in reference year has been taken as a starting point for future periods modelling. The calculation was applied to each of the nine industry subsectors to obtain detailed results for the main structure. Production for domestic market and import were directly linked, which meant that the production situation for domestic market could be significantly influenced by making changes in import trends. As a result, certain flexibility was added to the model where exact shares could be set. Production for export was directly regulated through determining amounts of export quantities for the reference year, which were obtained from the National Bureau of Statistics, and export change in the future periods. All possible outcomes of the energy consumption, whether the trend was rising or falling, were fully covered controlling the export in this manner. The exact amounts of production quantities determined the flexibility of export control.

Phasing out or introducing certain types of industry also played an important role because these changes could significantly influence the energy demand. The best example of phasing out is the textile industry which, in the last decade, has almost completely disappeared in certain EU countries. Efficiency component was considered to examine the influence of technology advancements on future energy demand. General structure and logics for calculating industry energy demand is presented in Figure 14.

The last major parameter was the fuel mix which provided the opportunity to further improve the future energy demand, according to the assumptions related to phasing out certain fuels and adding new, more environmentally friendly, alternatives as well as renewable energy sources. All four parameters were tested in the reference year to verify the suggested methodology which would be used later on for future energy demand predictions.

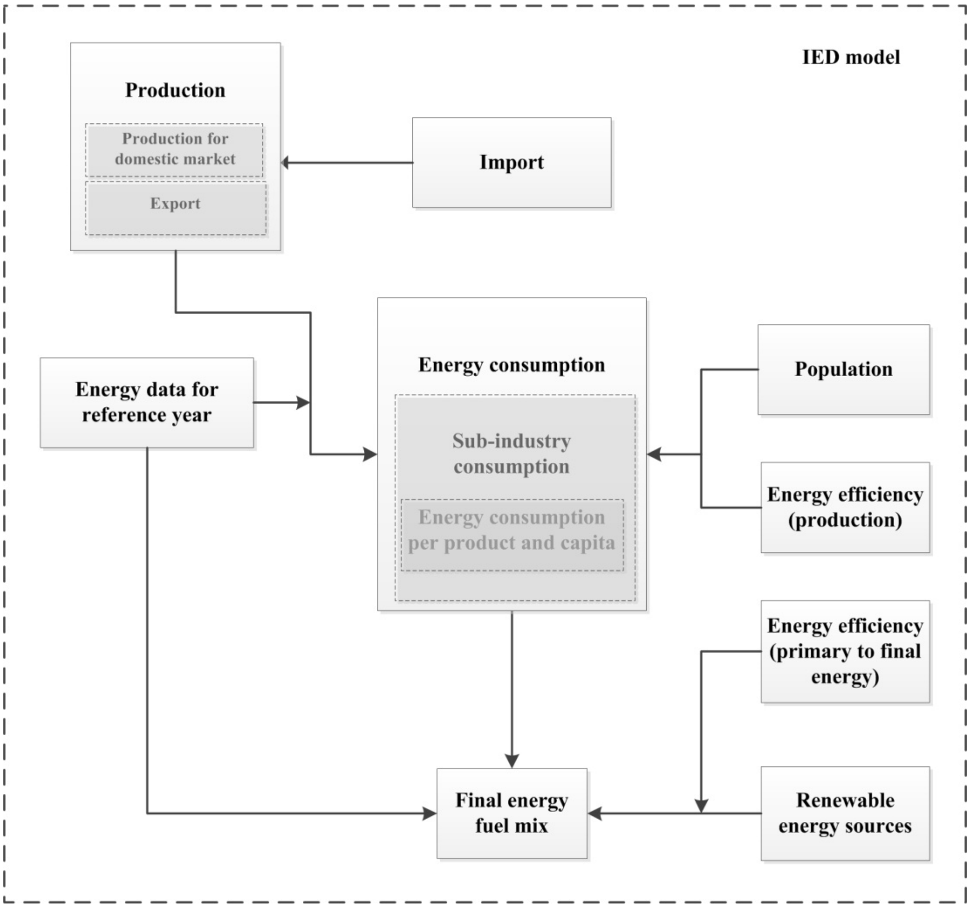


Figure 14 Overview of the IED model [119]

The IED model divides the industry sector in eight sub-sectors which are later on covered separately in order to describe all specific outcomes that might appear. The sub-sectors are:

- chemical industry
- construction materials industry
- food industry
- iron and steel industry
- non-ferrous metals industry
- non-metallic minerals industry
- paper and pulp industry
- other manufacturing industries

This methodology follows the official Croatian energy balance in order to have the possibility of modelling and obtaining the correct figures in the reference year. After testing, the IED model will be used to provide several possible future outcomes, i.e. scenarios to explore the variations in the final energy demand. The energy demand of each industry sub-sector yields an in-detail overview of barriers, specific energy related issues and opportunities which arise from current and future developments of the industry sector. Another important objective of this research is to compare the results with the official energy demand scenarios presented in the National Energy Strategy.

2.1.3.1 Population

For a complete overview of the industry sector, fluctuation of the population had to be considered due to influence on overall domestic production in all sectors. Input parameters for further consideration have been obtained from the National Bureau of Statistics. Approximate trends of population change have been set up differently considering a smaller population decrease. The visible trends in certain countries show that the majority of the population tends to move to bigger population centres. Population (N_{CAP}) for each respective year is used for calculating amounts of products per capita for each industry and later for obtaining results in production planning.

2.1.3.2 Production capacities

Domestic production capacities (including products for domestic market and export) have been obtained for each industry from the National Bureau of Statistics for the reference year. This information allows the user to calculate amounts of products per capita whose change will be later used to modify production capacities for domestic market along with import shares for each industry.

2.1.3.3 Final energy consumption

Final energy consumption data for each industry, according to previously shown classification, has been obtained from [160]. This data is used in further calculation modules to obtain specific energy consumption of each industry.

2.1.3.4 Primary energy consumption

Primary energy consumption data has been obtained from the National Bureau of Statistics to enable the user to manipulate the energy mix. Primary energy consumption and primary energy mix are also used for obtaining the corresponding final energy mix including application of renewable energy sources.

2.1.3.5 Consumption per capita

Consumption per capita has been integrated in this model with the purpose to incorporate the influence of population on product consumption. Consumption per capita in reference year has been taken as a starting point for future periods modelling. The calculation is applied to each industry to obtain detailed results for the main structure. Reference year values have been calculated as:

$$Q_{P,C} = \frac{Q_{P,D}+Q_I}{N_{CAP}} \tag{26}$$

Where: $Q_{P,C}$ - quantity of each product per capita in reference year [t/capita], $Q_{P,D}$ - total production quantity of each product for domestic market [t], Q_I - total import quantity of each product [t],N_{CAP} - total population
Previously shown equation is first applied to the reference year to establish a starting point.

Values ranging for other periods are calculated as:

$$Q_{P,Cx} = Q_{P,C} \cdot (1+ i_x) \tag{27}$$

Where: $Q_{P,Cx}$ - specific product consumption per capita in each year , i_x - defined change in consumption per capita [%]
Herein, i_x has a significant impact on energy consumption data, therefore changes in economic development can be presented in detail.

2.1.3.6 Production for domestic market and imports

Production for domestic market and import are directly linked which means that the user can, through making changes in import trends, significantly influence the production situation for domestic market. Such link/correlation adds certain flexibility to the model where exact shares can be set. However, the market situation in some industries is rather difficult to change due to small energy consumption. The highest impact on energy consumption is expected in industries where the share of domestic production is rather high and the consumption of product changes.

Production for domestic market is calculated as:

$$Q_{P,Dx} = Q_{P,Cx} \cdot (1 - i_{I,x}) \, N_{CAP} \tag{28}$$

Where: $Q_{P,Dx}$ - quantity of each group of products for domestic market in each year [t], $Q_{P,Cx}$ - specific product consumption per capita in each year [t/capita], $i_{I,x}$ - import share for specific industry [%]
Consequentially, production plans for each industry up to 2050 are made, including production for the domestic market which enables the calculation of energy demand.

The import quantities were calculated as:

$$Q_{P,Ix} = Q_{P,Cx} \cdot i_{I,x} \cdot N_{CAP} \tag{29}$$

Where: $Q_{p,Ix}$ - import quantity of each group of products

2.1.3.7 Production for export

Production for export is directly regulated through determining amounts of export quantities for the reference year, which were obtained from the National Bureau of Statistics, and export change in the future periods. Controlling the export in this manner allows one to fully cover all possible outcomes of the energy consumption, whether the trend is rising or falling. The exact amounts of production quantities determine the flexibility of export control. For example, some industries have small or very small export quantities, therefore if one was to examine the influence of increase of export quantities for purposes of generating additional energy consumption, previously imported data should be examined to determine the necessary value of increase to display a significant change in the respective industry. Additional flexibility of the designed model for export planning is obtained through separation of industry to branches where separate change trends can be set.

Production for export in periods that are predicted is calculated on the basis of the reference year, multiplied by the set change in the observed year.

$$Q_{P,Ex} = Q_{P,E,x-1} \cdot (1 - i_{E,x}) \qquad (30)$$

Where: $Q_{P,Ex}$ - export quantity of a product in the observed year [t], $Q_{P,Ex-1}$ - export quantity of a product in the previous year [t], $i_{E,x}$ - change in export quantities for the observed year in comparison to the previous year

2.1.3.8 Specific energy consumption

Specific energy consumption in the reference year is calculated from final energy data for each respective industry. This parameter directly influences final energy consumption of each respective industry, while taking into account the energy efficiency parameter. Energy efficiency has been set up as an input parameter where one can define the desired amount of increase in a desired period starting with the reference year. The distribution of percentages throughout the setup period will be linear.

$$E_{SP,ind} = \frac{E_{ind}}{P_{DOM}} \tag{31}$$

Where: $E_{SP,ind}$ - specific energy consumption of industry [MJ/t], E_{ind} - total final energy consumption of each industry [PJ], P_{DOM} - total amount of products produced within the industry, including both product quantities for domestic market and product quantities for export [t]

2.1.3.9 Increasing or decreasing energy demand

As previously explained, the total energy consumption of each industry throughout the observed period is calculated by taking into consideration the specific energy consumption for each industry together with consumption data per capita and population for each year. Also, the final energy consumption is influenced by the possibility to include new industrial plants or simulate closing of existing plants, both of which are expected disturbances in all industrial sectors. Addition or removal of plants is executed is such way so that the defined parameters influence final energy consumption in the selected year, as well as in the following periods, thus allowing to directly manipulate growth or downfall/decline of specific industry sub-sector.

2.1.3.10 Renewable energy sources

When determining all influential factors that will shape the future final energy demand, renewable energy sources must be considered as a serious alternative to conventional energy sources. The model has been set up to incorporate energy from renewable energy sources in each respective industry sub-sector. The exact increase in energy gained from renewable energy sources is an input parameter which is distributed in a linear fashion throughout the observed period. The calculation of energy gained from renewable energy sources was performed by calculating ratios of each fuel in final energy demand and multiplying the ratio by previously set increase in energy gained from renewable energy sources and final energy demand of each industry sub-sector in the reference year.

2.1.4 Services sector

Final energy demand of the services sector was calculated by summarizing all subsectors and their final energy demands. Service subsectors analysed through the NeD model were: education, tourism and catering trade sector, health, commerce and government. For the tourism and catering trade sector, the methodology presented in [102] was used. For the rest of the service subsectors the HED methodology [37] was mainly applied, adjusting certain parameters to capture all the specifics. For instance, when calculating final energy demand of the commerce and government subsector, energy for cooking was not included. Geographic distribution during calculation procedures was not set to the NUTS 3 level, like in the HED model applied to households, but at the NUTS 2 regional level. The available floor area was modelled based on the specific available surface per capita for different kind of service subsectors:

$$A_{i\ spec}^{z} = \frac{B_i^z}{P^z} \tag{32}$$

Where: $A_{i\ spec}^{z}$ - specific available surface of a certain category of a subsector in a specific year (e.g. hospitals, schools) [m^2/capita], B_i^z - available floor area of a certain category of a subsector in a specific year (e.g. hospitals, schools) [m^2], P^z – population in a specific year

After the available floor surfaces, outer envelope surfaces were calculated and basic thermodynamic equations for useful space heating/cooling demand, using the HED model equations, were set. Thermodynamic calculations were based on quantifying transmission and ventilation losses on one side and internal and solar gains on the other.

2.1.4.1 Sub-sector categories

The energy demand of the health subsector was calculated for eight different categories:

- Hospitals
- Institutes of public health
- Clinics
- Health centres
- Pharmacies
- Care organizations
- Other health institutions
- Health companies

These categories were chosen based on the statistics formed by the National Bureau of Statistics. This rule was applied to most of the modes because it allows for the NeD model to be validated by some future research and results. The difference in applying the HED model for the services sector was the way the outer buildings envelope surface was calculated. While for the households sector the outer buildings envelope surface was calculated by applying thermodynamic equations [37], for the services sector simpler approach had to be applied, due to a lack of quality data on available floor surfaces and building characteristics. When calculating available buildings outer envelope surface for the health, education, government and commerce subsectors average ratios between available floor area and outer envelope surfaces were calculated based on the gathered statistical information. Based on that information thermodynamic equations for useful heat and cooling demand, described in [37], were calculated.

The energy demand of the education subsector was calculated for four different categories:

- Kindergartens
- Primary schools
- Secondary schools
- Universities

The energy demands of the commerce and government subsectors were calculated for five different establishments depending on the number of employees. Chosen categories were:

- Establishments with 0-9 employees
- Establishments with 10-19 employees
- Establishments with 20-49 employees
- Establishments with 50-249 employees
- Establishments with 250+ employees

The main focus was given to the tourism and catering trade sector since its increase in activity, energy wise, was assumed. Based on that assumption individual model has been developed [102] and its methodology and calculation procedures were implemented into the NeD model. The methodology for calculating energy demand of the tourism and catering trade sector was based on determining energy transferred through the outer envelope surface and "other consumption", which contained various electric equipment, water heating, etc.

2.1.4.2 Translating households sector methodology

Floor surface in the tourism sector is determined from the data on the number of different types of objects and their properties regarding number and type of rooms and beds [145]. Number of housing units and beds, percentage of double, single and triple rooms, are important because the rooms have different floor surfaces. Number of rooms with certain number of beds in a county is determined by dividing the number of rooms in the county with the number of beds [145]. The floor surface is determined by multiplying the percentages of double, single and triple rooms with a percentage share of different types of units, for instance hotels or apartments, with basic square units of surface and the number of units in the county. Example of this calculation principle for the tourism sector floor surface is given through:

Table 2 Part of calculation principle for available surfaces of tourism sector (hotels)

Example	**Hotels 1***		
Zagreb county	H_{tou}	HU_{tou}	B_{tou}
	10	866	1936

$$B_{tou}/HU_{tou} = 2.0723 \tag{33}$$

Where: B_{tou}- number of beds, HU_{tou}- number of housing units

$$SQF = B_{Q2} \cdot HU_{tou} \tag{34}$$

Where: SQF- floor surface [m^2], B_{Q2}- basic square footage for two bed rooms [m^2]

Dividing beds with housing units determines whether the county will be calculated as a mostly one bed, two beds or three beds county. The basic data of square footage is available for one, two or three bed units. Table 2 shows how basic information on a number of objects, rooms and beds was tabled. Objects with different number of stars are separately calculated since the basic unit of square footage is different. The calculation differs when calculating different types of objects. The principle remains the same; however, different types of objects require different approaches.

Following example is given: as tourist settlement consists of different types of objects, B_{tou}/HU_{tou} ratio no longer directly defines the county as a one bed, two beds or three beds. It determines the added factor which is used to determine the scenario by which the county will be calculated, as described in equation 35.

Table 3 Part of calculation principle for available surfaces of tourism sector (tourist settlements)

Example	Tourist settlements 3*
Dubrovnik - Neretva county	SQF

$$B_{tou}/HU_{tou} = 2.245 \tag{35}$$

$$SQF = \left(AF \cdot B_{Q3} \cdot HU_{tou}\right)P_{SA} + \left(AF \cdot B_{Q2} \cdot HU_{tou}\right)P_{R} + (AF \cdot B_{Q3} \cdot HU_{tou})P_{A} \tag{36}$$

Where: AF- added factor, B_{Q3}- basic square footage for three bed rooms [m^2], H- number of hotels, P_{SA}- percentage of studio apartments [%], P_R- percentage of rooms [%], P_A- percentage of apartments [%]

AF determines the scenario by which the county will be calculated depending on B_{tou}/HU_{tou} ratio. Camps and marinas were not included in the estimation because it is too difficult to estimate their consumption. Basic floor surfaces for different types of housing units were obtained from regulations for minimal square units of surface and modified by using empirical data from the available sources to create a more realistic image. The floor surface of catering facilities was obtained by multiplying the number of different types of catering facilities with associated floor surfaces. Different types of catering facilities are divided according to the official categorization. Due to incomplete data and the similarity of some types of buildings, sometimes the same average surface represents few different types of objects. The number of different types of objects is determined for each county. Objects which fall under the catering or tourism sector are presented through Table 4.

Table 4 Overview of all establishments covered by the model

Catering sector

- Guest houses
- Motels
- Inn houses
- Rest stops
- Hostels
- Mountain houses
- Hunting lodges
- Eating houses
- Retreats
- Ship cabins
- Sleeping carts
- Restaurants
- Pubs
- Dining rooms
- Grill houses
- Bistros
- Fast food objects
- Coffee shops
- Night clubs
- All other catering units

Tourism sector

- Hotels
- Apart-hotels
- Tourist settlements
- Apartments

2.1.5 Agriculture sector

The agriculture sector usually represents a smaller portion of the nation's final energy demand. In Croatian case its about 4% of the final energy demand with 10.49 PJ in 2011 [84]. Even though it is not a very substantial amount because the agricultural activity is an important aspect of the country's economy, more detailed energy demand analysis had to be made. To calculate the energy consumption, the agriculture sector was first divided into the crop husbandry and animal husbandry subsectors. Both subsectors were then further divided into family farms and industrial farms, and finally onto specific productions (corn, wheat, barley, etc. for the crop husbandry; and cows, pigs, sheep and poultry for the animal husbandry).

2.1.5.1 Crop husbandry sub-sector

The energy consumption of the crop husbandry subsector was calculated according to equations 37 and 38:

$$EI_a = E_a / P_a \tag{37}$$

Where: EI_a – energy intensity of the agricultural production of a certain crop [MJ/t], E_a – energy intensity of the agricultural production of a certain crop [MJ/ha], P_a – crop productivity [t/ha]

$$EC_a = EI_a \cdot CP_a \tag{38}$$

Where: EC_a – energy consumption of the agricultural production of a certain crop [MJ/year], CP_a – crop production [t/year]

2.1.5.2 Animal husbandry sub-sector

The energy consumption of the animal husbandry subsector was calculated according to the following equation:

$$EC_{ah} = EI_{ah} \cdot NOE \tag{39}$$

Where: EC_{ah} – energy consumption of animal husbandry for a certain kind of animal [MJ/year], EI_{ah} – energy intensity of animal husbandry for a certain kind of animal [MJ/animal], NOE – number of animals [animal/year]

Historical data for the production of specific crops and the raising of certain animals were taken into account, as well as the ratio between small family and larger industrial farms. Calculated results were then compared to the data obtained from [84] and the difference between the two turned out to be negligible.

2.1.6 Construction sector

Although not usual in energy planning, the construction sector was included into the NeD model. The primary reason for this was to follow the national energy balance and national statistics and to allow similar future studies to compare the NeD results. The construction sector was usually included in the transport or industry sector when calculated with similar models. Energy demand model for calculating the construction sector was based on the national statistic which covered six main energy consumption categories: residential; non-residential; transport infrastructure; pipelines, communication and electricity lines; complex construction on industrial sites; and other civil engineering works. For every of the six mentioned categories fuel mixes were calculated: LPG, diesel, gasoline, electricity, heavy oil and renewable energy sources.

Equation 40 represents the main calculation procedure used for each fuel type in each energy consumption category.

$$F_{ij}^{z} = L_{ij\,spec}^{z} \cdot C_{j}^{z} \tag{40}$$

Where: F_{ij}^{z} - yearly energy demand of a different fuel type for a certain energy consumption category [PJ], $L_{ij\ spec}^{z}$- specific energy consumption of a different fuel type for a certain energy consumption category [PJ/m^2] [PJ/construction site], C_j^z – yearly property of a certain energy consumption category [m^2] [number of construction sites]

With i representing the fuel type and j representing the energy consumption category (residential, non-residential etc.). Based on the energy consumption category, units for the $L_{ij\ spec}^{z}$ and C_j^z were determined. If the calculation was made for residential and non-residential the units used were [PJ/m^2] and [m^2]. In case of other four energy consumption categories the units used were [PJ/construction site] and [number of construction sites].

2.1.6.1 Cross connection to households and services sector

Cross connection of the NeD model was visible through energy demand calculation of residential and non-residential energy consumption categories. All the newly build available floor surfaces that have been calculated in the households and services sectors were imported into the construction sector model as an input data. Based on this data energy needed for constructing all those new floor areas was calculated.

2.1.7 Greenhouse gas emissions modelling

Only CO_2 emissions from all six economic sectors were calculated in the current version of the NeD model. After the energy demand and the fuel mix were calculated for every sector, this information was imported into the GHG mode. So every energy policy that would influence future energy demand would at the end influence future CO_2 emissions as well. The GHG mode was structured based on the IPCC[3] parameters. IPCC data for every fuel, in tCO_2/TJ were used. These data were default, but different sets of data could be imported into the model if necessary. When it came to electricity, all electricity from all six economic sectors was summed up and then the national conversion factor for electricity ($kgCO_2/kWh$)

was applied. The conversion factor, which depends on the country was imported into the model as an input data. This conversion factor was dependant on the electricity generation fuel mix and could vary from year to year. This is the case especially in countries relying strongly on hydro power. In the process of calculating GHG emissions of district heating, national conversion factor was also applied (kgCO$_2$/kWh).

The basic principle of GHG calculation can be presented by the following equation:

$$G_i^z = S_i^z \cdot K_i^z \tag{41}$$

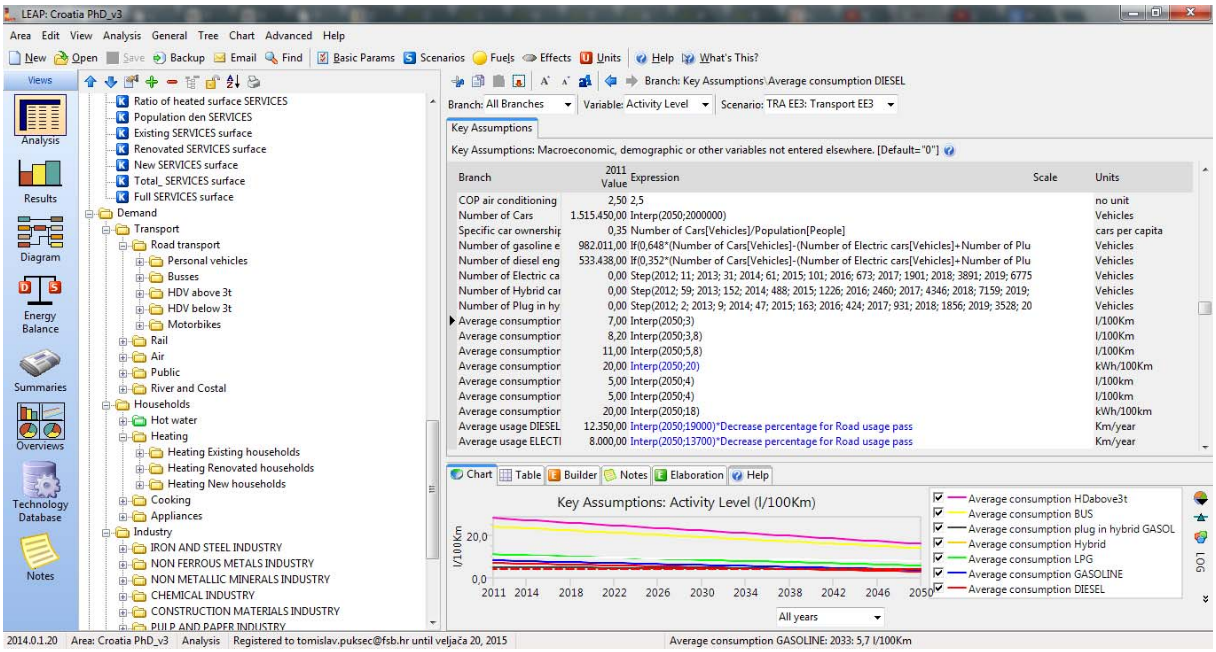
Where: G_i^z - yearly amount of CO$_2$ emitted from a certain fuel type [tCO$_2$], S_i^z - specific CO$_2$ emission conversion factor of a certain fuel [tCO$_2$/GJ], K_i^z - yearly amount of various fuel consumed [GJ]

Where i represents the fuel type for which the emitted CO$_2$ was calculated while the conversion factors were basically set depending on the fuel observed.

2.2 LEAP model

In order to partially test the developed NeD methodology, a scenario based computer tool, Long Range Energy Alternative Planning System (LEAP) was chosen. Another reason for testing the NeD methodology, in the limits of the LEAP model, is to provide a simpler and more user friendly tool that can be more easily used by policy makers or other energy planners. LEAP is an accounting tool that has the ability to match demand with supply-side energy technologies. In the case of this research, LEAP is primarily used as an energy demand tool.

One of the biggest advantages of the LEAP model is its easy to use scenario-based modelling software for energy planning. It presents a clear and a visual “point and click” energy planning tool, which makes it easy to use (Figure 15). It is not a model of a particular energy system, but a modelling tool. Another main advantage of this model is its low need for initial input data. It also allows using both energy demand planning approaches; top down and bottom up, as well as their combination. No matter which is the chosen approach, the model follows a strict hierarchical regime which starts with the energy demand planning and ends with available resources, with transformation in between. One of the key features of LEAP, used in this research, is the scenario manager tool. In this case various policy measures could be tested and certain parallel can be drawn to the NeD model. As a downside of this model, possibility to model energy demand on a higher level of complexity could be identified. This especially presents a problem when detailed geographical distribution is necessary in the case of buildings stock or when any kind of energy demand calculation is necessary, on time frames lower than one year. Also, as the case model becomes bigger and more complex, the model loses parts of its functionality and user friendliness.



Branch: Key Assumptions\Average consumption DIESEL

Branch: All Branches Variable: Activity Level Scenario: TRA EE3: Transport EE3

Key Assumptions: Macroeconomic, demographic or other variables not entered elsewhere. [Default="0"]

Branch	2011 Value	Expression	Scale	Units
COP air conditioning	2,50	2,5		no unit
Number of Cars	1.515.450,00	Interp(2050;2000000)		Vehicles
Specific car ownershi	0,35	Number of Cars[Vehicles]/Population[People]		cars per capita
Number of gasoline e	982.011,00	If(0,648*(Number of Cars[Vehicles]-(Number of Electric cars[Vehicles]+Number of Plu		Vehicles
Number of diesel eng	533.438,00	If(0,352*(Number of Cars[Vehicles]-(Number of Electric cars[Vehicles]+Number of Plu		Vehicles
Number of Electric ca	0,00	Step(2012; 11; 2013; 31; 2014; 61; 2015; 101; 2016; 673; 2017; 1901; 2018; 3891; 2019; 6775		Vehicles
Number of Hybrid car	0,00	Step(2012; 59; 2013; 152; 2014; 488; 2015; 1226; 2016; 2460; 2017; 4346; 2018; 7159; 2019;		Vehicles
Number of Plug in hy	0,00	Step(2012; 2; 2013; 9; 2014; 47; 2015; 163; 2016; 424; 2017; 931; 2018; 1856; 2019; 3528; 20		Vehicles
Average consumptior	7,00	Interp(2050;3)		l/100Km
Average consumptior	8,20	Interp(2050;3,8)		l/100Km
Average consumptior	11,00	Interp(2050;5,8)		l/100Km
Average consumptior	20,00	Interp(2050;20)		kWh/100Km
Average consumptior	5,00	Interp(2050;4)		l/100km
Average consumptior	5,00	Interp(2050;4)		l/100km
Average consumptior	20,00	Interp(2050;18)		kWh/100km
Average usage DIESEL	12.350,00	Interp(2050;19000)*Decrease percentage for Road usage pass		Km/year
Average usage ELECTI	8.000,00	Interp(2050;13700)*Decrease percentage for Road usage pass		Km/year

2014.0.1.20 Area: Croatia PhD_v3 Analysis Registered to tomislav.puksec@fsb.hr until veljača 20, 2015 Average consumption GASOLINE: 2033: 5,7 l/100Km

Figure 15 Implementation of the simplified NeD methodology into LEAP

LEAP has been used in more than 150 countries [146]. One of their main applications is for reporting to the U.N. Framework Convention on Climate Change (UNFCCC) [147]. LEAP was used in many studies and reports, both on a national and regional scale; California [148], Venezuela [149], Korea [150], Bangkok [151], Thailand [152], Beijing [153], China [154], Taiwan [125] and Lebanon [155].

2.3 Case study

2.3.1 Sectoral to national level results

Both energy demand models, NeD and LEAP were used to test the developed methodology with the Republic of Croatia as a case study. The NeD model results were compared to the Croatian National Energy Strategy and Primes EU28 results, which have been recently available as well as to the simplified case study of Croatia, done in LEAP.

3 RESULTS AND DISCUSSION

3.1 National energy Demand model: Croatia

Throughout this chapter main results calculated by the NeD model will be presented. All six economic sectors will be covered, together with the associated GHG emission. Finally, the results of the simplified NeD methodology implementation in LEAP will be presented. To fill in the NeD model various data sources were used: Croatian energy balance[14], the Croatian National Bureau of Statistics, EUROSTAT, different databases such as Odyssee[15] or IPCC. For every sector input data sources vary, but the ones mentioned are standard.

3.1.1 Households sector

In every energy demand planning focused on buildings, the key issue is to create a two level model (working on useful and final energy level). This way all measures focused on the physics of the building could be quantified on the useful energy level, while all "technology" measures could be quantified on the transition between useful and final energy. One of the main intentions of this research was to investigate and present the influence of future energy regulations regarding renovation and nearly zero energy buildings. In Figure 16 heat demand for the reference scenario is presented with the yearly renovation rate of 1% and with classifying all new buildings entering the households stock as "nearly zero energy buildings" after the year 2021. Every building renovated after 2021 is also considered a "nearly zero

---

[14] Energija u Hrvatskoj - http://www.mingo.hr/default.aspx?id=3258

[15] http://www.indicators.odyssee-mure.eu/energy-efficiency-database.html

energy building”. This means they still consume energy, but that energy has to be produced locally from a renewable energy source. “Nearly zero energy buildings” as well as buildings renovated to “nearly zero energy” standard are used to show potential energy savings and potential for the implementation of distributed renewable energy sources [26]. The year 2021 was chosen based on the energy performance of building directive deadlines regarding the NZEB implementation. Certain prolongation regarding refurbishment to “nearly zero energy” standard is expected in Croatia, but this effect in not quantified here. The NeD model has the possibility of choosing any year after which new or renovated buildings are built on “nearly zero energy” standard and is left to the person using the model to decide.

In Table 5 average U-values for walls and average monthly temperatures used in the calculation are presented. Thermal transmittance values are taken from [156] and have been calculated by UNDP Croatia based on the conducted energy audits in various Croatian counties. Average monthly temperatures for 21 Croatian counties have been calculated based on the biggest city of the county, for which the values existed in [157]. For instance, in the case of Varaždin county, the City of Varaždin was chosen. If there was no data on the biggest city of the county available in [157] the nearest city for which the data exists was taken. For instance, in the case of Virovitica-Podravina county the chosen city was Daruvar. Thermal transmittance of windows is taken as 3 W/m^{2}K for all counties. Every new building built or renovated after the reference year (from 2012) is calculated with the thermal transmittance of 1.8 W/m^{2}K which is linearly decreasing every year to 0.7 W/m^{2}K in the year 2050. The same logic is used for the thermal transmittance of walls. Every new building built or renovated after the reference year is presumed to have 0.5 W/m^{2}K (for every county) which is linearly decreased to 0.15 W/m^{2}K in 2050.

In Table 6 and Table 7 most important input data for modelling Croatian households sector are presented. When it comes to solar irradiation average monthly data have been calculated based on the following principle. Since it is very difficult to assess the window orientation for the whole county, arbitrary data were used: 55% of windows are facing south, 30% east and west and 15% are facing north. This is a very simplified assumption, but it was the only option since available data are nonexistent.

Table 5 Average U-values and average monthly temperatures used in the calculation

		Monthly average temperatures per county (^{0}C)											
County	U_{aver} (W/m^{2}K)	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Continental Croatia	1.217												
City of Zagreb	1.181	1.00	2.90	7.10	11.70	16.80	20.30	21.90	21.30	16.30	11.40	6.50	1.40
County of Zagreb	1.189	1.00	2.90	7.10	11.70	16.80	20.30	21.90	21.30	16.30	11.40	6.50	1.40
County of Krapina-Zagorje	1.922	0.30	2.60	6.50	11.30	16.30	19.70	21.10	20.20	15.30	10.90	6.10	0.90
County of Varaždin	1.132	0.40	2.20	6.40	11.20	16.20	19.60	21.20	20.50	15.50	10.70	6.00	0.80
County of Koprivnica-Križevci	1.057	0.50	2.40	6.60	11.60	16.60	20.00	21.50	20.80	15.70	10.90	6.00	0.90
County of Međimurje	0.991	0.40	2.20	6.40	11.20	16.20	19.60	21.20	20.50	15.50	10.70	6.00	0.80
County of Bjelovar-Bilogora	1.226	0.50	2.60	7.00	11.90	17.10	20.60	22.10	21.40	16.00	11.20	6.20	1.00
County of Virovitica-Podravina	1.226	0.80	2.40	6.50	11.20	16.30	19.80	21.40	20.70	15.60	11.10	6.40	1.40
County of Požega-Slavonia	1.144	0.30	2.50	6.90	11.60	16.80	20.10	21.60	21.00	16.30	11.60	5.90	1.50
County of Brod-Posavina	1.144	0.30	2.40	7.00	11.90	16.90	20.40	22.10	21.50	16.20	11.30	6.30	1.20
County of Osijek-Baranja	1.246	0.20	2.20	6.50	12.00	17.50	20.60	22.10	21.70	16.30	11.60	6.30	1.10
County of Vukovar-Srijem	1.233	0.20	2.20	6.50	12.00	17.50	20.60	22.10	21.70	16.30	11.60	6.30	1.10
County of Karlovac	1.203	0.50	2.40	6.80	11.40	16.50	20.00	21.70	21.00	15.70	10.90	6.10	0.90
County of Sisak-Moslavina	1.144	0.90	3.00	7.30	12.00	17.00	20.50	22.10	21.30	16.10	11.40	6.60	1.40
Adriatic Croatia	1.533												
County of Primorje-Gorski Kotar	1.097	5.90	6.30	9.20	12.90	17.90	21.60	24.30	24.10	18.90	14.70	10.4	6.80
County of Lika-Senj	1.097	0.60	0.70	4.50	8.80	14.00	17.70	19.60	19.20	13.70	9.80	5.20	0.20
County of Zadar	1.697	7.50	7.50	10.1	13.50	18.40	22.30	24.80	24.50	20.10	16.40	12.2	8.60
County of Šibenik-Knin	1.896	7.10	7.50	10.4	13.80	19.00	23.00	25.70	25.30	20.40	16.40	11.9	8.10

County of Split-Dalmatia	1.907	8.20	8.30	11.0	14.50	19.80	23.90	26.60	26.40	21.20	17.30	12.7	9.10
County of Istria	1.130	6.00	6.20	9.10	12.80	18.10	22.20	24.90	24.50	19.50	15.40	11.0	7.20
County of Dubrovnik-Neretva	1.907	9.40	9.30	11.5	14.40	19.20	23.10	25.50	25.70	21.60	18.00	13.8	10.4

Table 6 Solar irradiation values used to calculate monthly averages

Adriatic Croatia (kWh/m^2)	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
South	85.83	103.06	116.39	100.28	93.61	87.78	94.72	104.44	118.33	134.72	95.00	80.28
East. West	40.00	56.94	88.06	106.39	125.56	132.50	138.89	123.33	100.83	79.72	45.28	35.00
North	17.78	22.50	36.94	46.39	57.78	58.89	58.33	51.67	38.61	28.61	18.61	15.56
Continental Croatia (kWh/m^2)	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
South	43.61	57.78	86.11	83.61	87.78	83.61	90.28	94.17	99.72	88.06	45.56	32.22
East. West	23.61	35.56	66.94	86.39	110.56	116.11	121.94	106.94	84.72	55.56	25.56	17.22
North	14.17	20	35	45.28	57.78	59.44	59.44	51.67	37.78	26.67	15.28	11.39

Table 7 Input data for household sector modelling

Inside temperature (^{0}C)	Wall percentage (%)	Window percentage (%)	Internal heat gains (W/m^2)	Percentage of heated space (%)	Ratio of air exchange (1/h)	Energy for hot water heating (kWh/m^2)	Height of a ceiling (m)
22	75	25	4.5	43	1	18.15	2.4

3.1.1.1 Nearly zero energy buildings

The renewable energy that would need to be produced locally is presented by marked surface in Figure 16. Reference scenario calculates the specific floor area in square meters per resident with a total increase of 20% from the year 2011 till 2050. This is done so an increase in floor area per resident could be presented. An increase of this yearly renovation rate to 2% is presented in Figure 17. As a result of the increased renovation of buildings, a significant increase in useful energy demand, which would be necessary to supply locally from renewable energy sources, is expected. This increase in the year 2050 is 48% higher if comparing 1% to 2% renovation rate scenario.

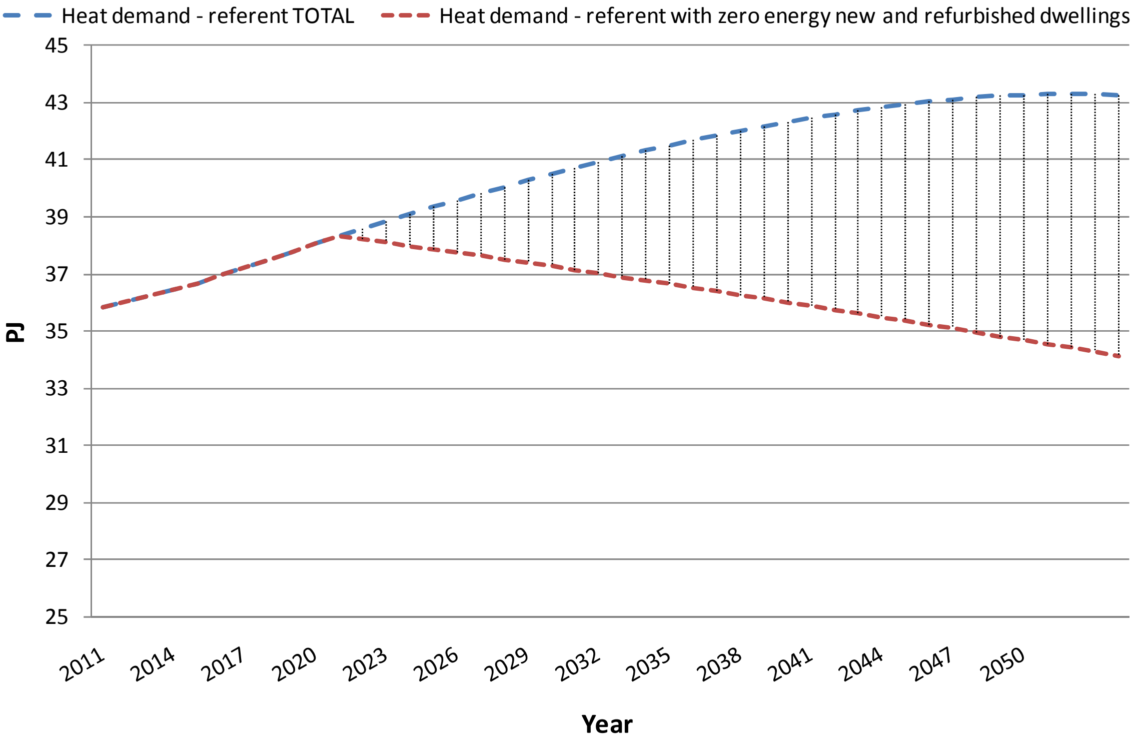


Figure 16 Useful energy demand for heating with 1% renovation rate and 20% increase in living space

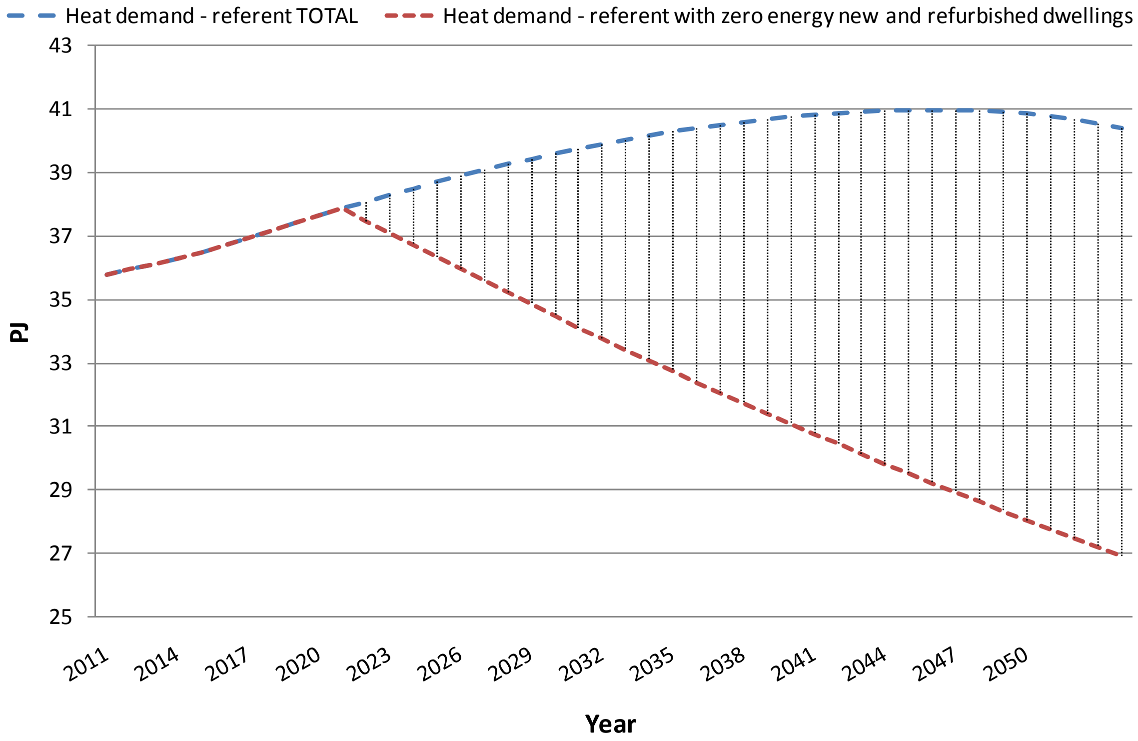


Figure 17 Useful energy demand for heating with 2% renovation rate and 20% increase in living space

Renovation rate presents an important parameter since it directly influences future heat or cooling demand. In Figure 18 different heat demands are presented depending on the applied yearly renovation rates. This is the case if all new and renovated buildings would strictly follow current and future building codes. As can be seen from Figure 18, the renovation rate could be a significant parameter in planning future energy demand of the households sector. In Croatian case the difference in heat demand for the year 2050 between 1% and 3% yearly renovation rate is almost 12%. When calculating thermodynamic characteristic, whether regarding heat or cooling demand, including solar gains turned out to be a significant component. It was confirmed that without consistent solar gains calculation, heat and cooling demand cannot be compared well with the official energy balance [14]. Important aspect was to test unknown variables in order to safely use them in the forecasting calculation.

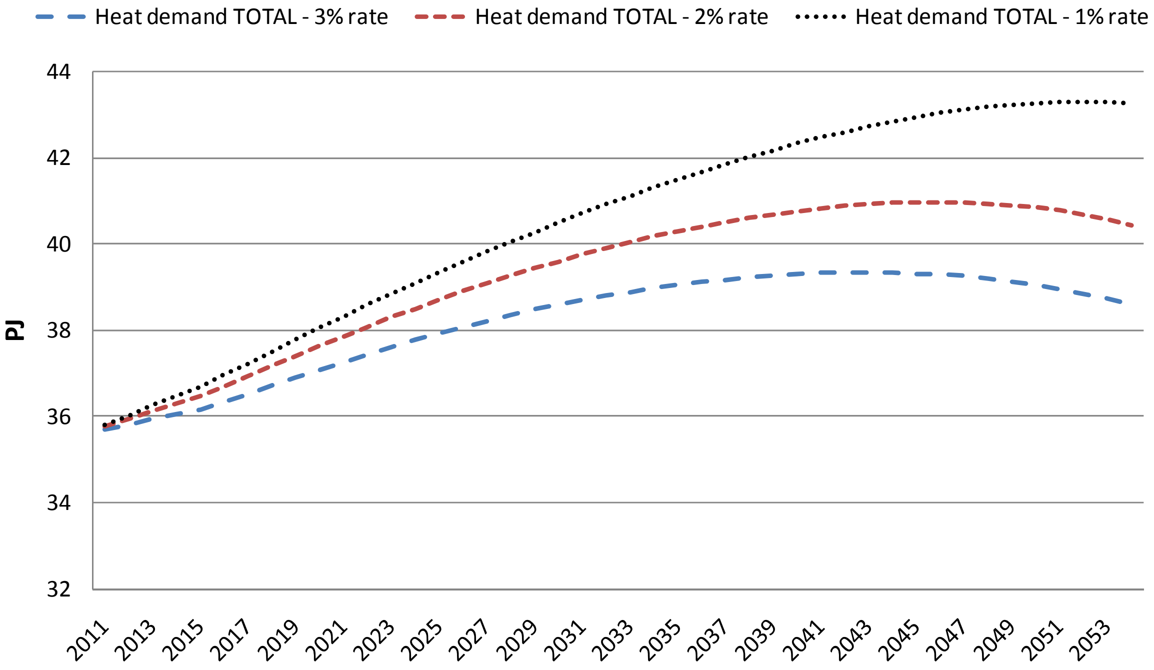


Figure 18 Useful heat demand depending on the yearly renovation rates

Results connected to heat demand are presented because space heating, with a share of 57%, is the highest energy consumer of Croatian households sector [84].

In Figure 19 the reference scenario with the final energy demand of all sub-categories is presented. The reference scenario is modelled based on current building codes and with the presumption that people are complying with current building codes strictly. The reference scenario in Figure 19 and Figure 20 presents final energy demands together with new and renovated “nearly zero energy buildings” energy demand. The reference scenario does not include migration between Croatian counties, but assumes constant share ratios, calculated in the reference year. After energy used for heating, the most significant sub-category is appliances which uses electricity for its operation. In the reference scenario energy efficiency improvements of appliances are taken in correlation with the Primes EU28 results [28]. This includes small increases of energy efficiency; 2% linear decrease in specific consumption (kWh/m^2) in 2030, in comparison to 2011, and an additional 13% linear decrease in 2050.

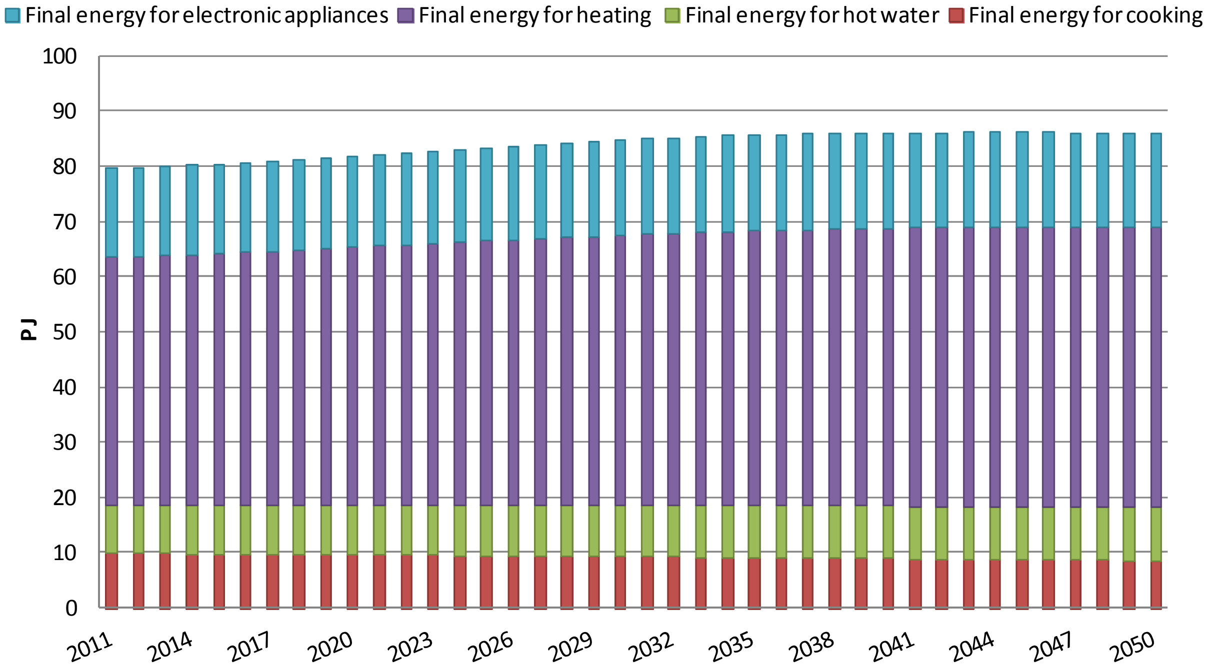


Figure 19 Households final energy demand – Reference scenario till 2050

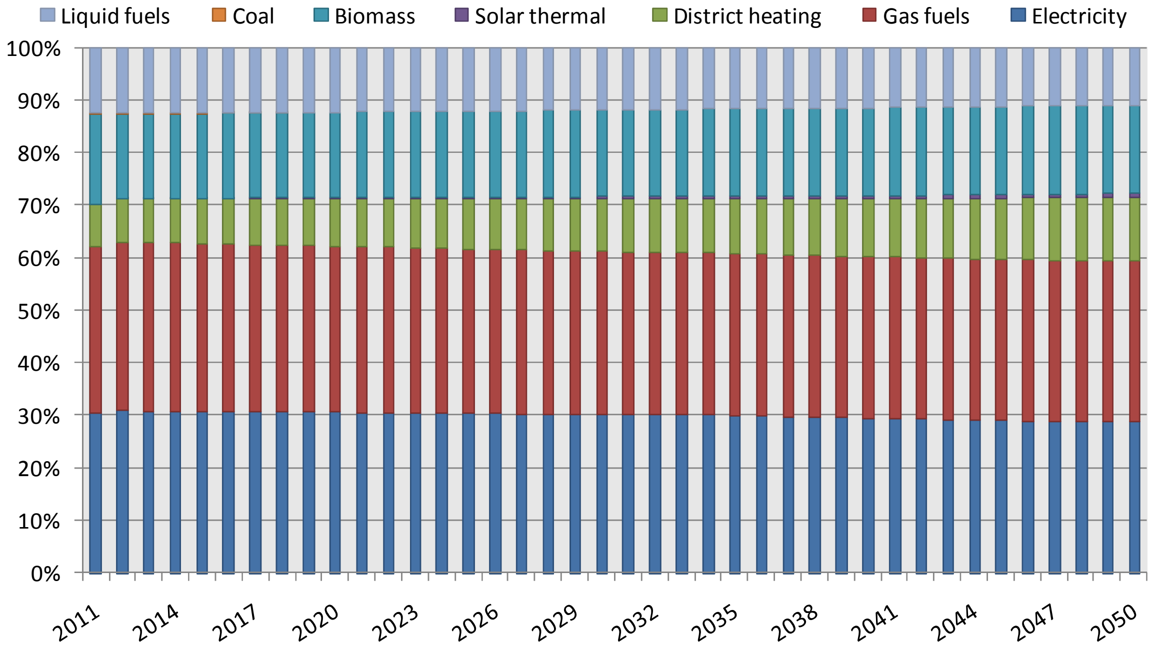


Figure 20 Households final energy demand – Reference scenario fuel mix till 2050

3.1.1.2 Hourly useful heat demand

Since the NeD model can calculate hourly heat and cooling demand for every year until 2050 it gives an additional opportunity to test the monthly calculation method, but also gives a valuable input for future advanced energy systems analysis (Figure 21). Hourly data (temperatures and solar irradiation on the NUTS 3 level) were taken from METEONORM [156]).

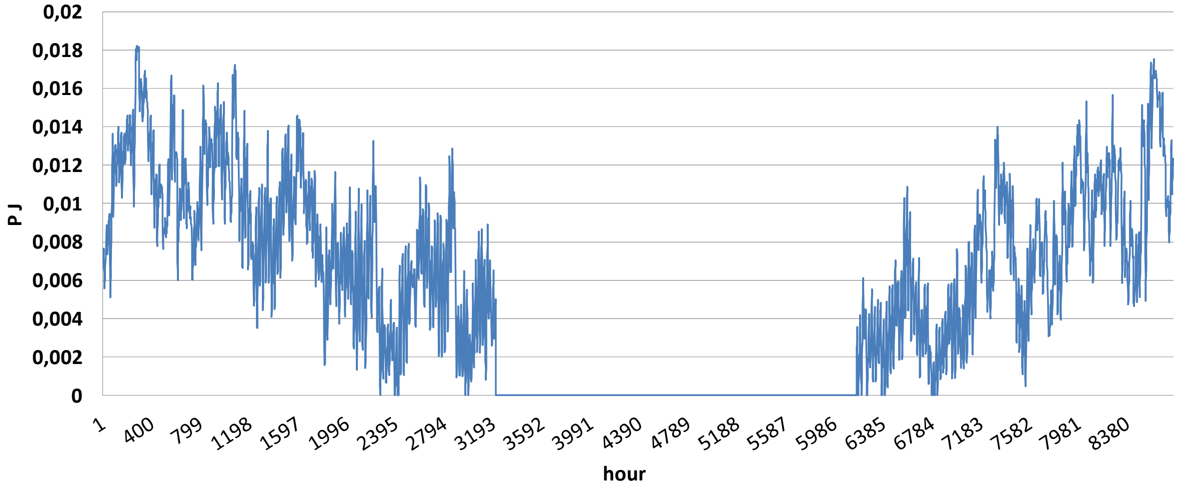


Figure 21 Hourly useful heat demand – Reference scenario for the year 2030

3.1.1.3 Three scenario analysis

The focus of this research is on the final energy demand projections. Fuel mixes are calculated throughout this model in order to have a unified and meaningful demand representation, fuel wise. Energy storage (whether regarding heat or electricity) and its dynamics would be very important in the final energy demand distribution, however, this research would fit under the domain of advanced energy systems analysis.

When testing the NeD model three future energy demand scenarios were made for the purposes of this thesis: biomass option (EE1 scenario), district heating option (EE2 scenario) and heat pumps option (EE3 scenario). In the EE1 scenario biomass is used to satisfy 50% of the useful energy for heating in 2050, while in the EE2 scenario 50% of the useful energy demand is satisfied by district heating. In the EE3 scenario heat pumps are used to satisfy 50% of the useful energy for heating in 2050. Another difference between these scenarios is the yearly renovation rate presumed; in the cases of EE1 and EE2 the yearly renovation rate is set to 2%, while in the EE3 scenario the rate is set to 3%. These options are applied to space heating section, while cooking and hot water are set to the reference scenario values. Increase of energy efficiency of various appliances is modelled in the following way; the EE1 and EE2 scenarios presume 50% linear decrease of specific consumption (kWh/m^2) in 2030 and an additional 20% linear decrease in 2050. In the EE3 scenario this linear decrease is 75% in the year 2030 and an additional 10% in 2050. Large electric appliances are modelled with the linear decrease of 10% in the year 2030, with an additional 10% in the year 2050, for the EE1 and EE2 scenarios. For the EE3 scenario, these linear decrease is 30% till 2030, and an additional 10% till 2050. Finally, small electric appliances are modelled with 20% linear decrease of specific energy consumption in the year 2030 and an additional 20% in the year 2050 in the EE1 and EE2 scenarios. In the EE3 scenario the linear decrease in 2030 is set to 30%, with an additional 20% decrease in 2050.

Transition between useful and final energy for heating is based on technology efficiency. In the reference year (2011) efficiencies for fossil fuels were taken from 60% for coal to 80% for natural gas. Electrical resistance heating is taken as 100% efficient, while district heating is taken as 95%. For fossil fuels 10% increase in efficiency is presumed in 2050 while the heat pumps COP is set to 4 in 2050.

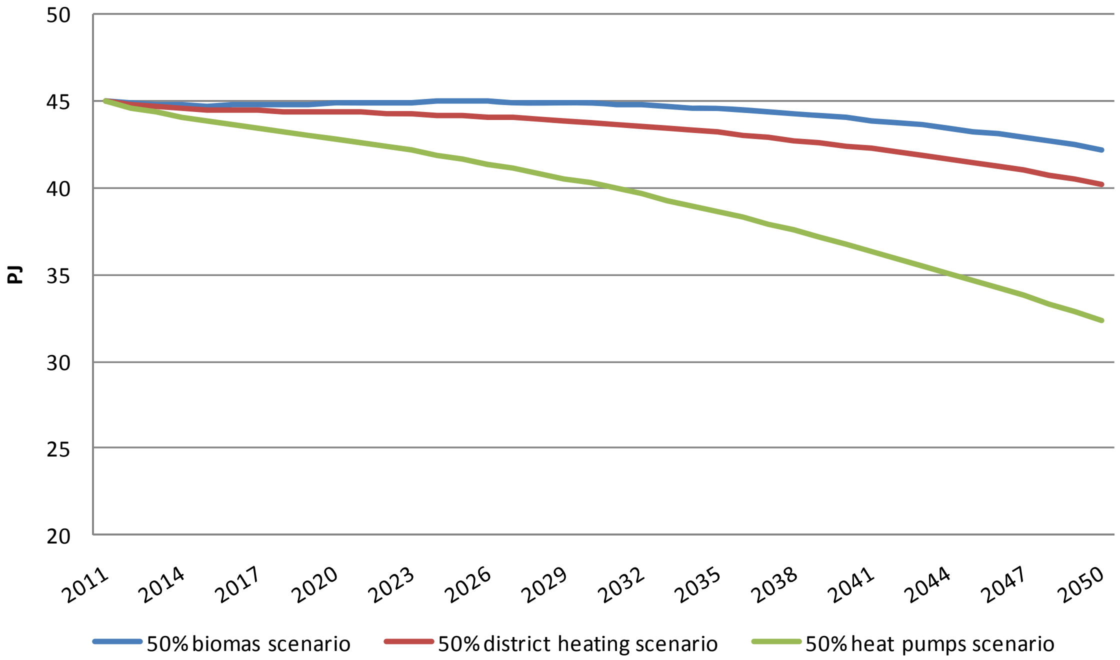


Figure 22 Final energy demand for space heating – Three scenarios (EE1, EE2 and EE3)

3.1.1.3.1 Biomass option

In Figure 23 energy demand of the biomass scenario is presented while Figure 24 gives share ratios of different fuels of the same scenario. In this case the biomass option would increase total final energy demand when comparing it to the reference scenario since in the reference scenario we had a more unified distribution of technologies and fuel types. In the technology scenarios, chosen technology represents 50% of satisfied useful energy demand in the 2050. In this case the rest is satisfied with heat pumps and district heating. Coal, natural gas and classing electrical heating are phased out in 2050.

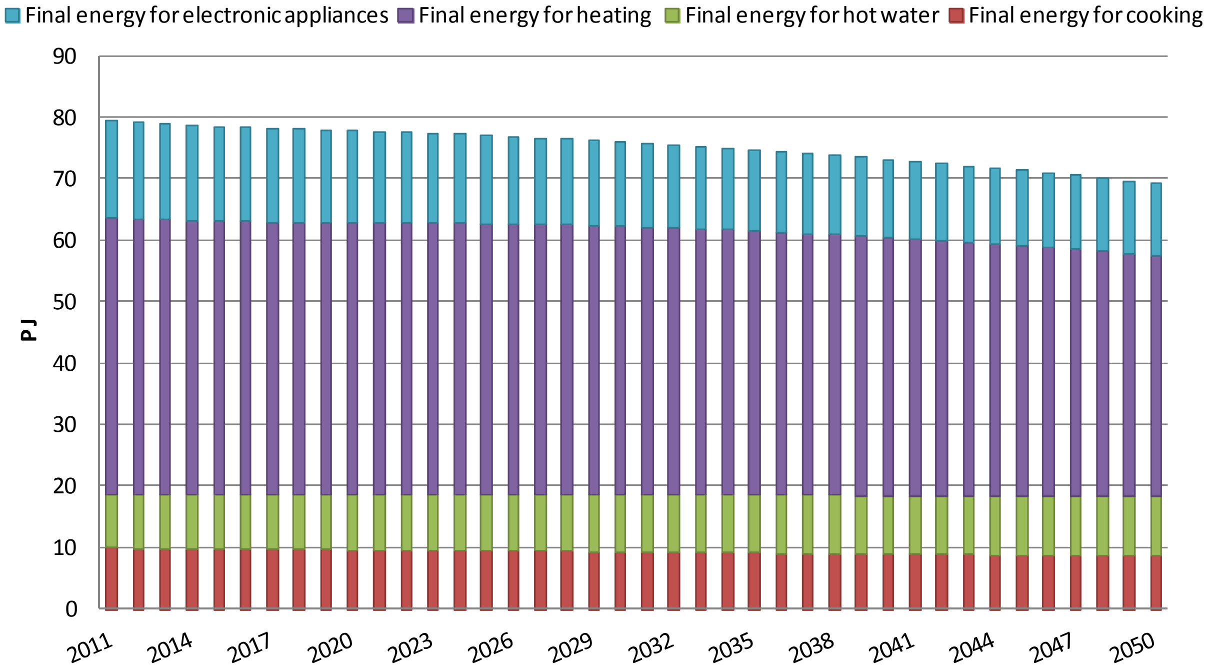


Figure 23 Final energy demand EE1 scenario – biomass option with 2% renovation and energy efficiency improvements

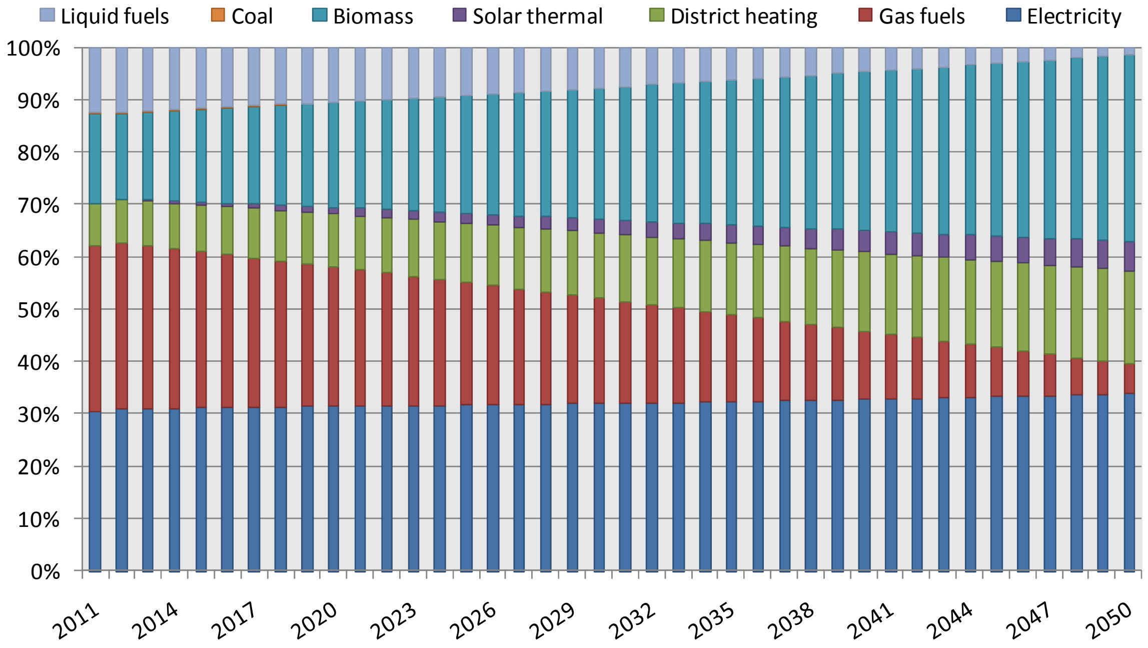


Figure 24 Final energy fuel share EE1 scenario – biomass option with 2% renovation and energy efficiency improvements

3.1.1.3.2 District heating option

Similar situation happens with the district heating option regarding final energy demand (Figure 25), while fuel shares change in favour of district heating (Figure 26). The same fuel mix share policy applies as in the previous scenario. The NED model calculates final energy demand for district heating solely because of available data received from the Croatian energy balance [1]. For all future versions of the NED model, more detailed structure of district heating, primarily types of fuel used, is needed.

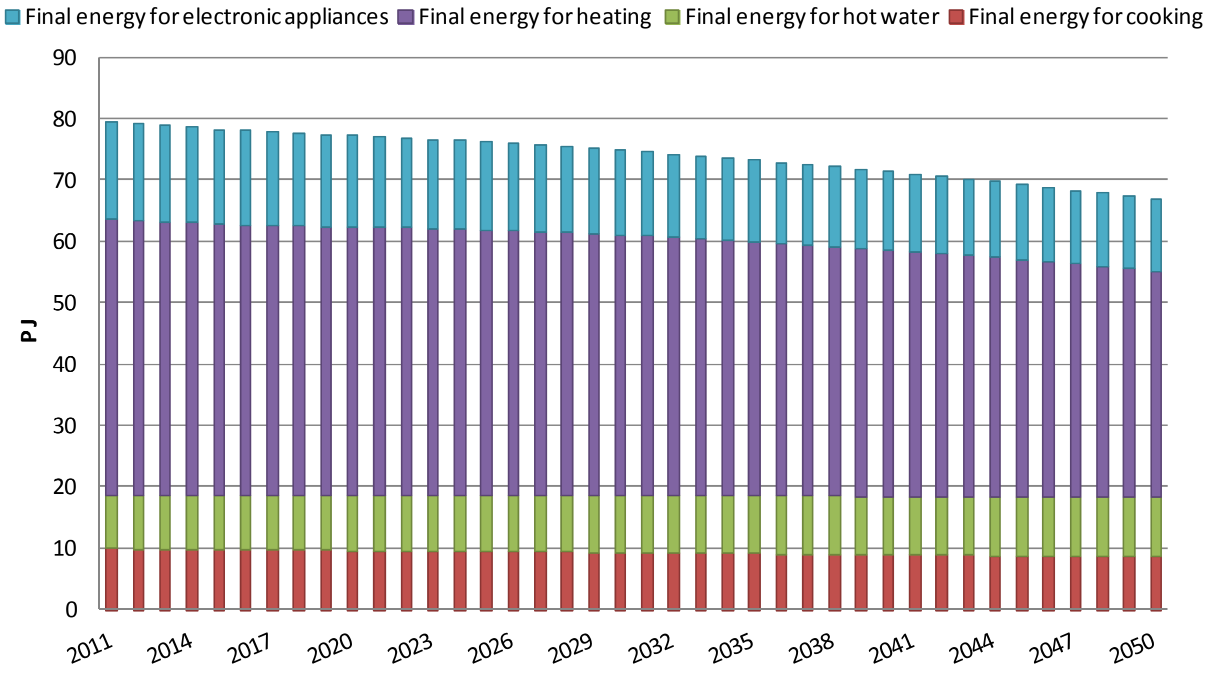


Figure 25 Final energy demand EE2 scenario – district heating option with 2% renovation and energy efficiency improvements

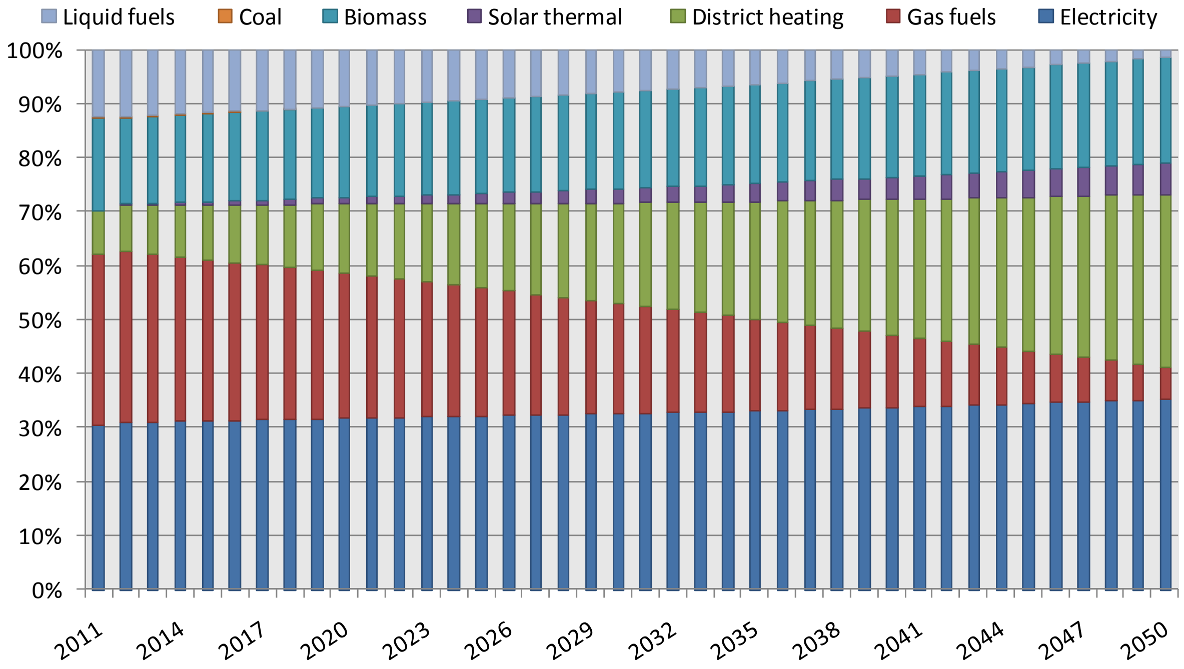


Figure 26 Final energy fuel share EE2 scenario – district heating option with 2% renovation and energy efficiency improvements

3.1.1.3.3 Heat pumps option

High penetration of heat pumps would lead to an increase of electricity consumption in the future period. In this scenario their share in 2050 is 50% in satisfying useful heat demand. However, this electricity could be produced locally and from renewable energy sources. In the year 2030 the heat pumps option could lower the final energy demand significantly. If compared with the biomass option these savings could go up to 8 PJ with a possible increase till 2050 to 14 PJ (Figure 27), as the renovated buildings stock becomes more expressed. Future building stock, tending to be passive or nearly zero energy will have a hard time achieving this without heat pumps. In this case, the biggest increase in the fuel mix is in the area of electricity (Figure 28) but if compared to other previous options final energy consumption has the biggest fall in the year 2050, due to high heat pumps efficiency.

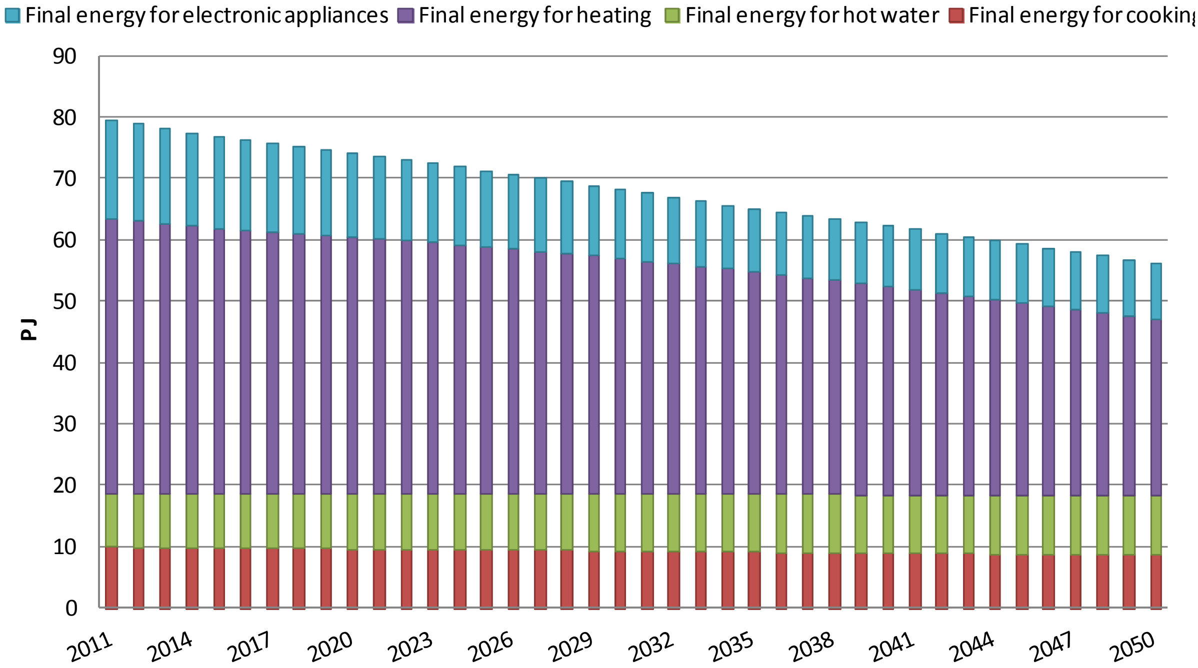


Figure 27 Final energy demand EE3 scenario – heat pumps option with 3% renovation and energy efficiency improvements

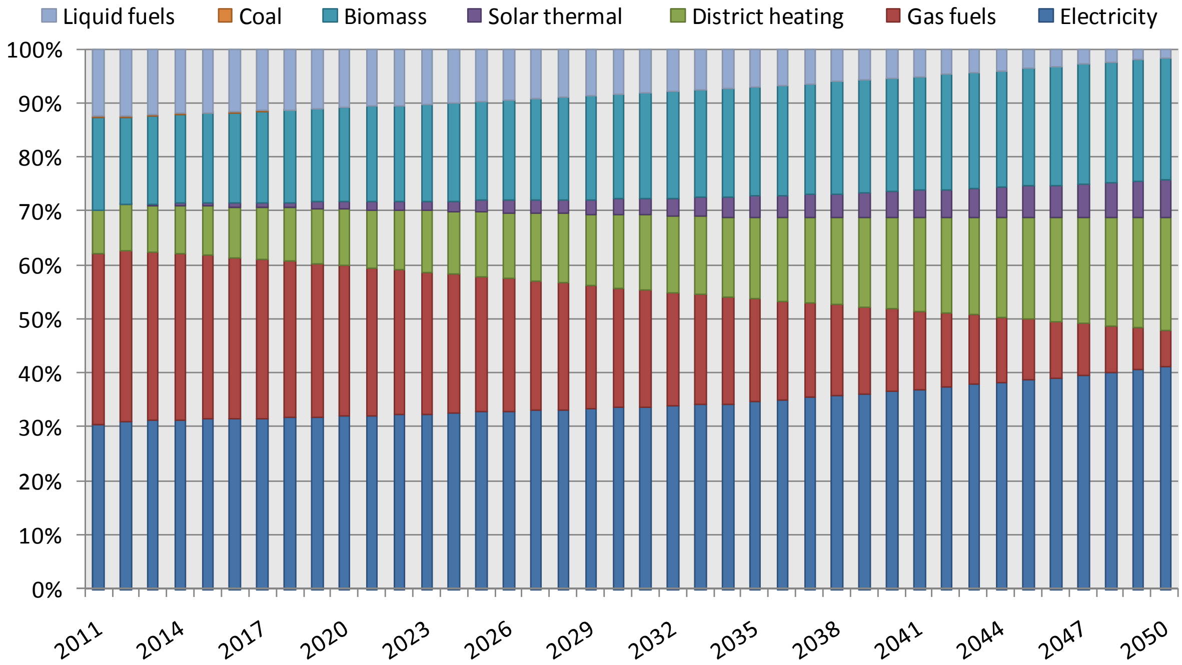


Figure 28 Final energy fuel share EE3 scenario – heat pumps option with 3% renovation and energy efficiency improvements

3.1.2 Transport sector

Setting the reference year is the first step in calibrating the NeD model. As for all other sectors, 2011 was chosen as the reference year. The basic input data for all five sub-modes are given in Table 8 and Table 9. The most common energy indicators used in the model construction are shown in Table 10.

Table 8 Transport of passengers and goods in the reference year [159]

Railway transport		Road transport		Seawater and coastal transport		Inland waterway transport	Air transport	
Passengers carried, ('000)	Goods carried, ('000 t)	Passengers carried, ('000)	Goods carried, ('000 t)	Passengers carried, ('000)	Goods carried, ('000 t)	Goods carried, ('000 t)	Passengers carried, ('000)	Goods carried, ('000 t)
49 983	11 794	52 561	74 645	12 926	30 348	5 184	2 078	3

Table 9 Passenger kilometres and tonne kilometres in the reference year [159]

Railway transport		Road transport		Seawater and coastal transport		Inland waterway transport	Air transport	
pkm	tkm	pkm	tkm	pkm	tkm	tkm	pkm	tkm
1 486	2 438	3 145	8 926	583	155 437	692	1 591	2

Table 10 Most common energy indicators used when constructing the NeD model [159]

Road transport of goods per tonne-km, (toe/tkm)	Energy consumption of road transport per equivalent car, (toe/careq)	Specific consumption of cars, (l/100 km)	Unit consumption of air transport, (toe/passenger)	Energy efficiency gains in transport since 2000, (%)
0.064	0.78	7.29	0.057	13.8

Most of the input data used in the NeD model are directly taken from the Croatian Bureau of Statistics [159] and the Croatian energy balance [84]. Statistically, the Croatian transport sector is well covered, which allows an end-use level of modelling (Table 11, Table 12 and Table 13).

Table 11 Main properties of Croatian road transport in the reference year [159]

Number of road vehicles						
Total	Out of total					
		Passenger cars				
	Motorcycles	Total	Privately owned	Light vans	Buses	Goods vehicles
1 969 405	62 876	1 518 278	1 353 252	-	4 841	154 884
Number of road vehicles entering the transport system						
Total						
	Motorcycles	Passenger cars		Light vans	Buses	Goods vehicles
66 290	2 726	48 883		-	173	5 198

Table 12 Air transport information for the reference year [159]

Aircraft fleet

Total number	Passenger seats	Net aircraft loading capacity,(kg)	Aircraft-kilometres flown, ('000)	Number of working flights
16	1 789	183 020	19 527	29 868

Passenger and freight data

Passengers carried, ('000)		Passenger-kilometres, (mln)		Freight carried, (t)		Tonne-kilometres, ('000)	
Total	International traffic	Total	International traffic	Total	International traffic	Total	International traffic
2 078	1 571	1 591	1 430	3 347	2 230	2 293	1 959

Table 13 Urban transport data for the reference year [159]

Trams				Buses			
Number	Passenger seats	Kilometres travelled, ('000)	Passengers carried, ('000)	Number	Passenger seats	Kilometres travelled, ('000)	Passengers carried, ('000)
394	59 350	16 150	173 177	1 196	114 669	70 655	191 205

3.1.2.1 Scenario analysis

For the purposes of this research, five different energy demand scenarios are presented and analysed. The first scenario involves frozen energy efficiency (Frozen efficiency scenario) throughout the modelling period. This is done solely for the purpose of comparing possible energy savings in case of different energy efficiency mechanisms.

The next scenario is the reference one (Reference scenario) which includes mild linear energy efficiency improvements. It follows conservative assumptions of Primes EU28 about energy efficiency evolvement [28]. The third scenario (EE1 scenario) involves the implementation of the current EU legislation regarding the energy efficiency of internal combustion engines. Of course, this scenario would not actually require extra efforts since Croatia would feel this effect through vehicle imports. Learning curves regarding the energy efficiency of internal combustion engines have been done based on McKinsey research which calculated consumption equivalents based on EU CO_2 emission requirements [160].

The fourth scenario (EE2 scenario) presents the option of the electrification of personal vehicles till the year 2050. This is a very interesting scenario because it offers insight into possible energy savings and reduced dependence on foreign fossil fuels in case Croatia decides to switch to electrification. This would present a significant impact on the country's electricity demand, meaning new infrastructure and technologies both on the transmission and distribution side [161].

Finally, the fifth scenario (EE3 scenario) presents an even better energy efficiency solution because it implies a further modal split from road and air transport to rail in the forthcoming period. For the purposes of this research, the start of the modal split has been set to the year 2015.

In Figure 29 all five energy demand scenarios can be seen. If left with no technology development, the energy demand of the Croatian transport sector would reach 148 PJ, which is an increase of almost 73% compared to that of the reference year, with an assumption of 50% increase of the specific car ownership in 2050 compared to reference year (vehicles/capita). If an increase in the energy efficiency of personal vehicles is applied (EE1 scenario), which is in line with the EU regulation on CO_2 emissions, the energy consumption in the year 2050 can be lowered by 42%. Further improvements, in terms of energy consumption, that are in line with the electrification of the personal vehicles fleet, could lead to an additional 23% in energy savings when compared to the EE1 scenario, implementing the EU energy efficiency legislation. Finally, if an additional modal split is added to the electrification scenario, an additional 13% of energy can be saved in the year 2050. Comparing the zero efficiency scenario with the modal split scenario, the total possible energy savings in the Croatian transport sector in the year 2050 can reach nearly 99 PJ, or 62%.

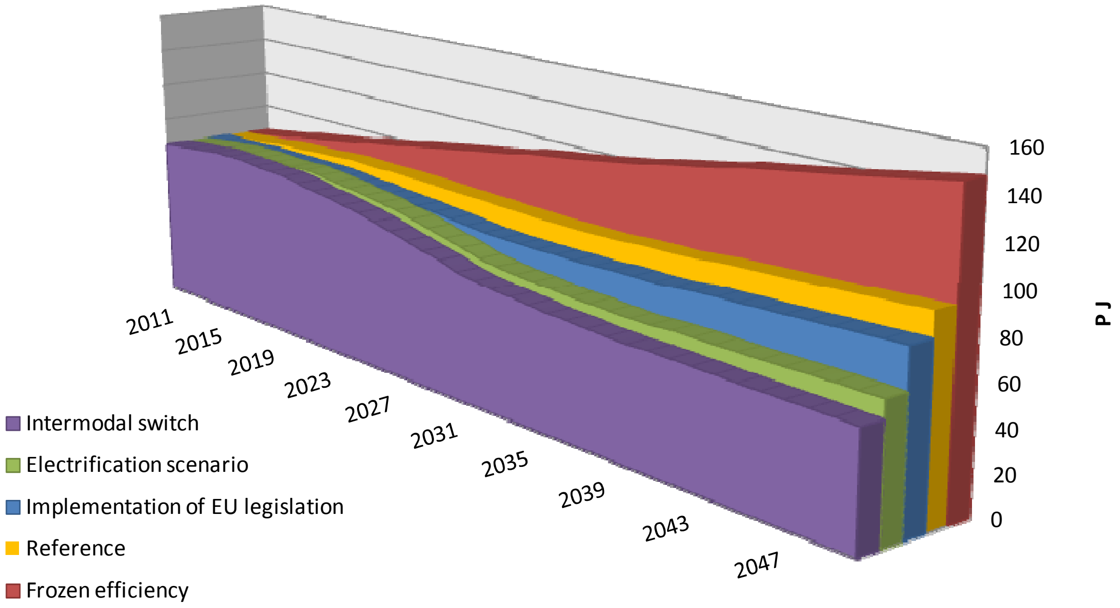


Figure 29 Five long term energy demand scenarios of Croatian transport sector

As probably the most interesting scenario, here the electrification scenario is described in greater detail. All four scenarios were calculated based on the same number of personal vehicles in the system, which would account for approximately 2 million vehicles in the year 2050 (Figure 30). The main intention of Figure 30 is to show potential trends in the implementation of electric vehicles based on a different scenario approach. Based on the methodology presented in Chapter 2.1.2.1, the total number of personal vehicles was calculated by accounting for the entrance and exit of personal vehicles in the system. As a safety check, specific car number (cars/capita) was used, which, as shown in Figure 30, indicated an increase of 50% in specific car number from the reference year to the year 2050. To have fewer parameters and variables in all four scenarios presented in Figure 29, a reference scenario was used for all the subsectors while the road transport subsector was modified.

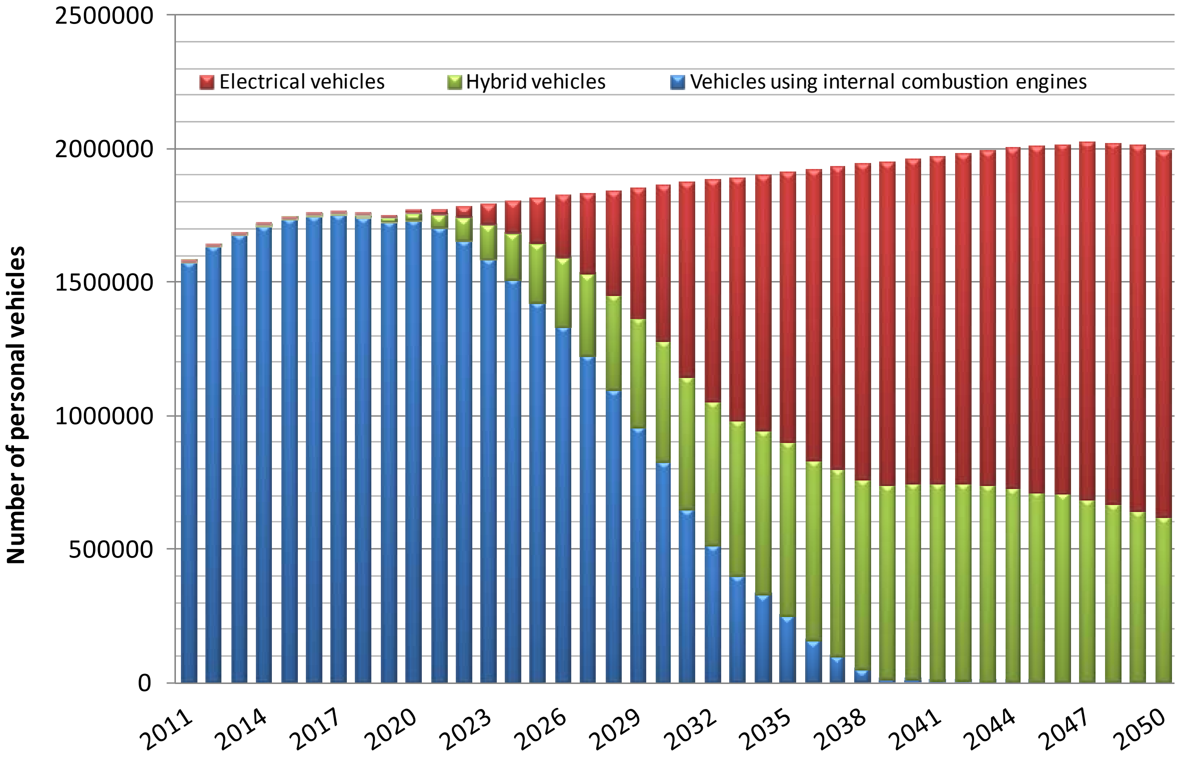


Figure 30 Personal vehicle distribution of the EE2 scenario – Electrification scenario

In the reference scenario, the main focus is on technology switches among different vehicles present in the system, which has a direct influence on energy demand. The energy efficiency issue is also considered which influences future energy demand significantly, as shown in Figure 31 and Figure 32.

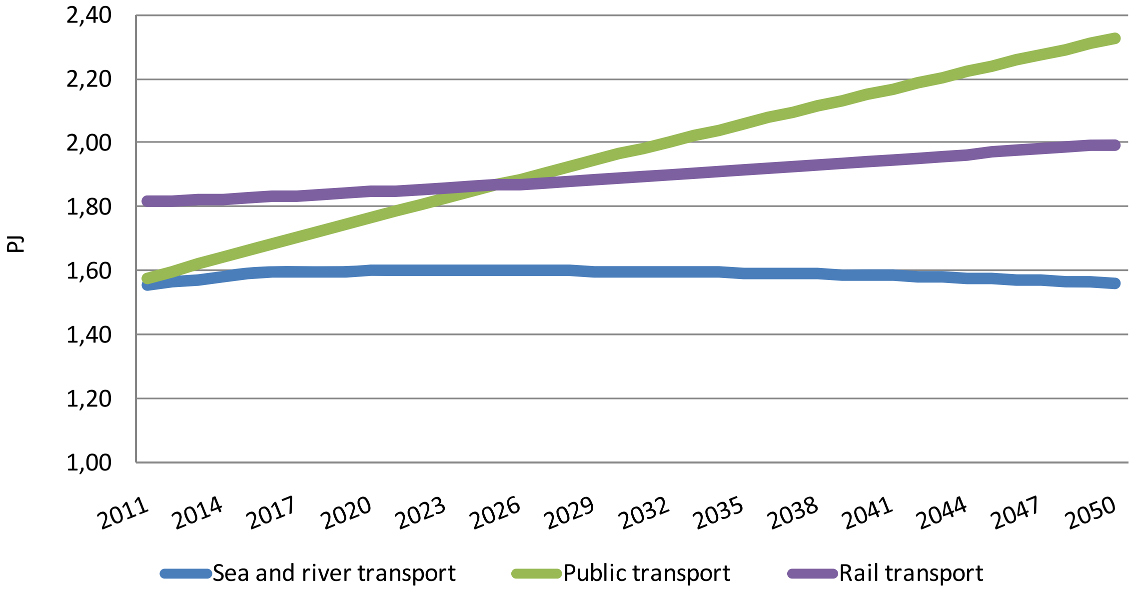


Figure 31 NED model reference scenario for rail, public and sea and river transport

Based on the reference scenario, the only three subsectors that experience an increase in energy consumption, beyond future energy efficiency improvements, are public, rail and air transport. The increase in energy consumption in public transport is due to a great motivation for public transport improvement, which is in line with the increased fleets, routes and total number of passengers using this type of transport. Air transport increases as a result of a constant Croatian strive towards the expansion of the tertiary sector (Figure 32). Interesting results are shown in Figure 31, specifically, a very mild increase in energy demand in the rail subsector. Despite a significant increase in traffic, the continuous electrification of this subsector leads to a small increase in its long-term energy demand.

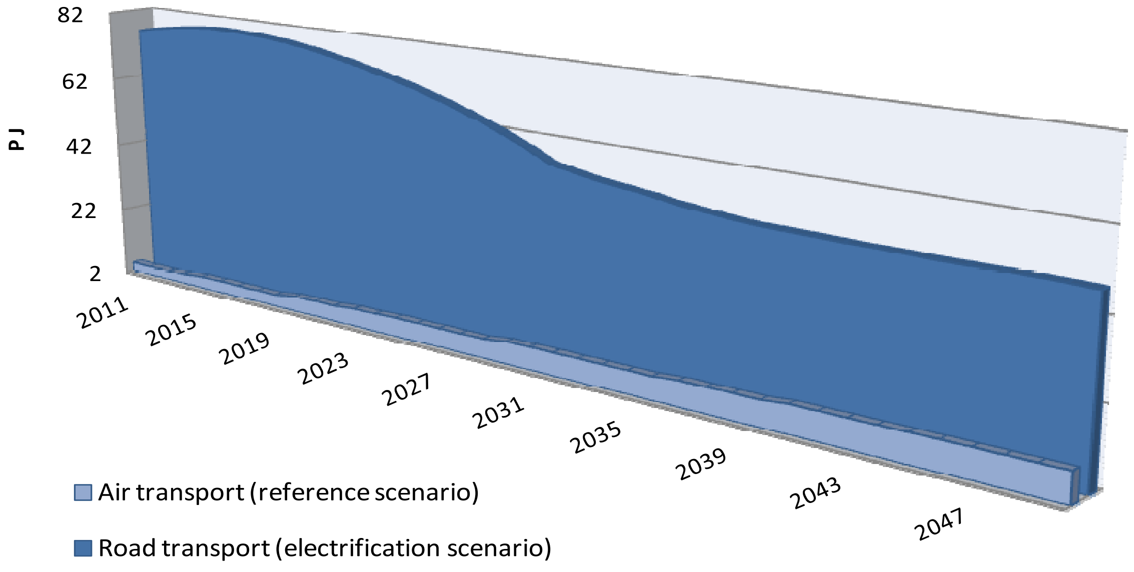


Figure 32 NED model reference scenario for the air transport and electrification scenario (EE2 scenario) for the road transport

3.1.2.2 Vehicle dynamics

Perhaps the most interesting parameter when comparing the electrification scenario with the other scenarios is the fleet size regarding electric personal vehicles and its effect on the total final energy demand of the transport sector.

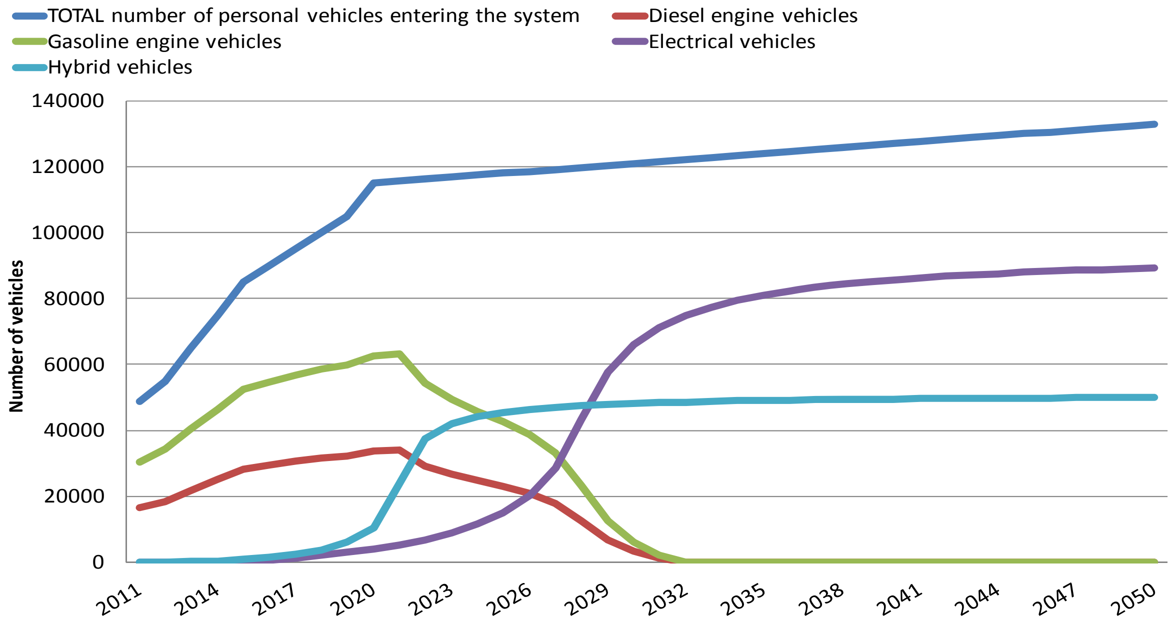


Figure 33 New personal vehicles entering the system every year (EE2 scenario)

The dynamics of alternative personal vehicle penetration and the total number of such vehicles in the system are shown in Figure 33 and Figure 34. The highest market penetration of electric vehicles is assumed to occur by the end of the 2020s, while hybrid vehicle penetration is assumed to occur almost an entire decade earlier (Figure 33).

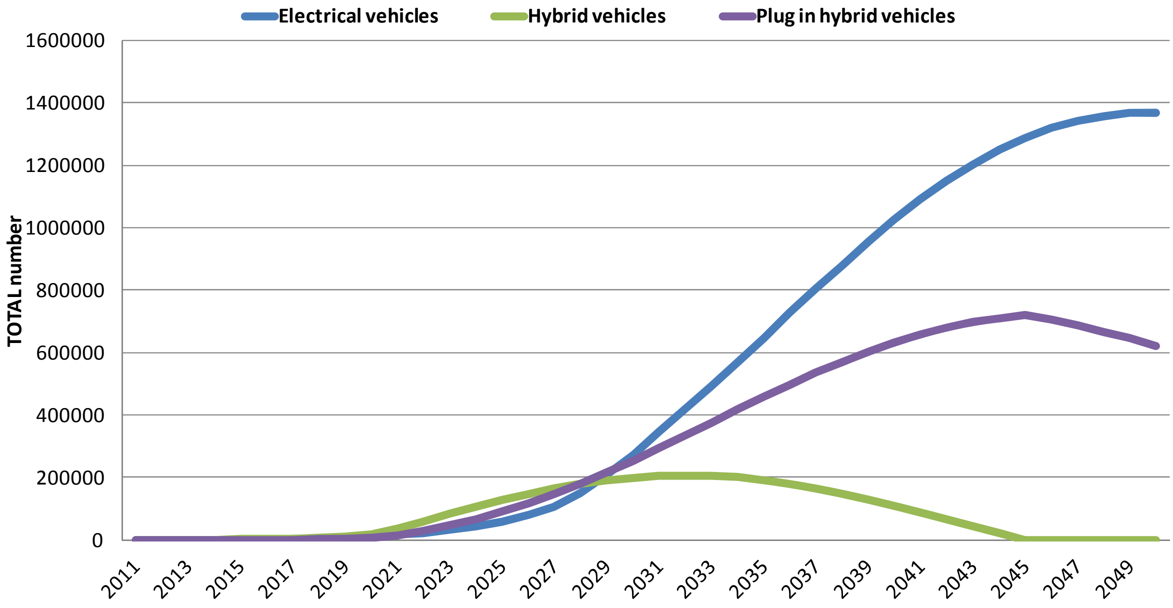


Figure 34 Number of electric and hybrid personal vehicles in Croatia till 2050 (EE2 scenario)

An interesting comparison, visible in Figure 35, is the energy consumption of internal combustion personal vehicles in 2011 and the energy consumption of alternative personal vehicles in 2050. Around 1,5 million ICE personal vehicles in 2011 (Table 11) consumed around 45 PJ, while almost 2 million alternative personal vehicles (electric and plug in hybrid) would consume merely 11 PJ in 2050.

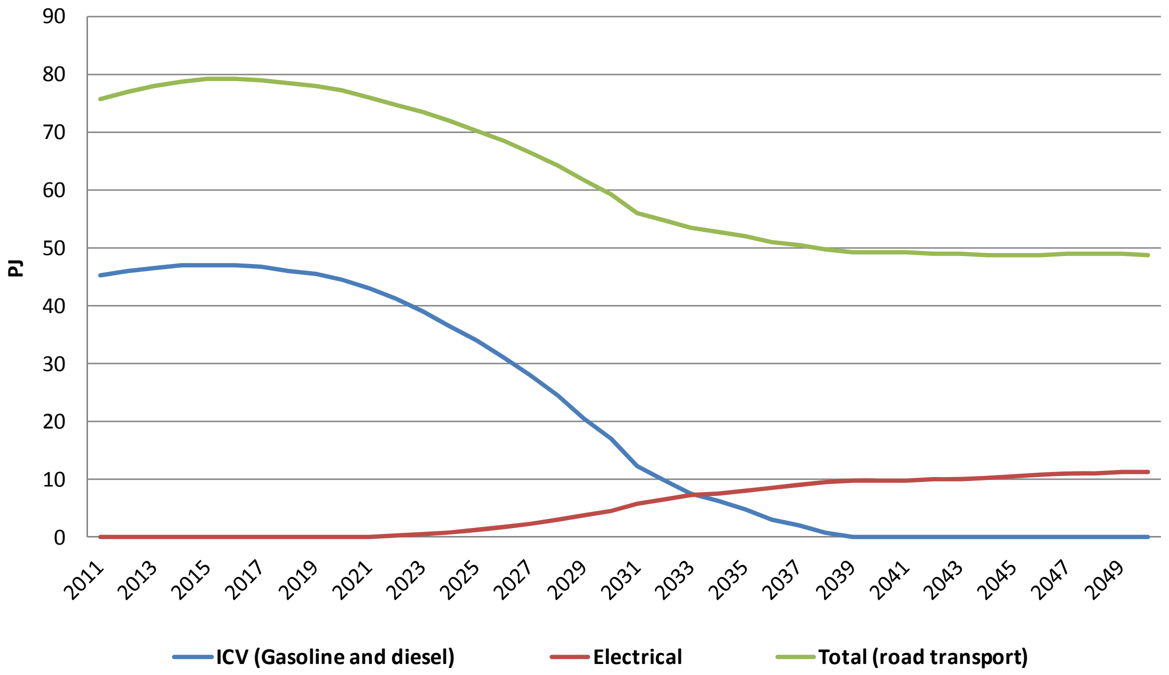


Figure 35 Energy consumption of personal vehicles depending on the technology (EE2 scenario)

With the increase of the specific car number by 50%, the electrification scenario assumes a steady increase in the number of electric personal vehicles till 2050 to almost 1.4 million. In the same scenario, plug in hybrid vehicles would account for around 600 000 vehicles (Figure 30). In the year 2045, a phase out of conventional hybrid vehicles can be seen, with plug-in vehicles being the only hybrid vehicles left in the system. In the EE2 electrification scenario, hybrid vehicles, together with electric vehicles, become the backbone of personal vehicle road transport after 2040.

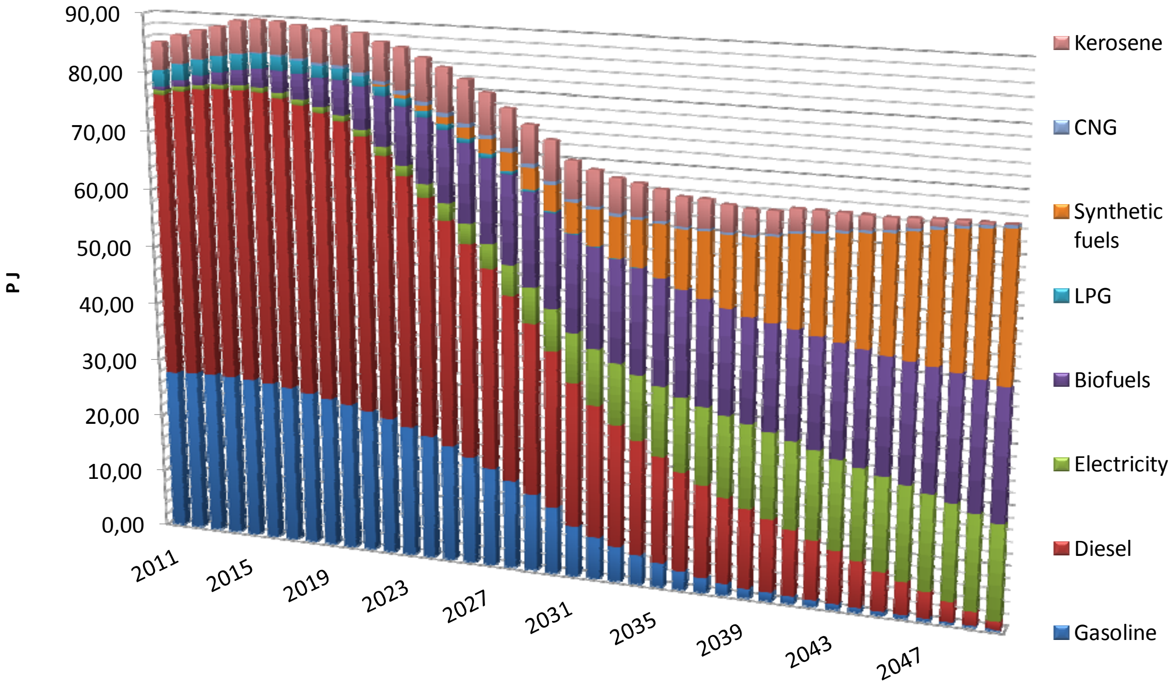


Figure 36 Fuel mix of Croatian transport sector – EE2 electrification scenario

In Figure 36, the different fuel mixes of the entire transport sector are presented for the electrification scenario. The electrification of personal vehicles substantially affects the total final energy demand. In Figure 37, the fuel mixes of only road transport, without any electrification of the personal vehicles subsector, are presented. When comparing Figure 36 and Figure 37, it can be concluded that the road transport alone, without any electrification, exhibits 24% higher energy consumption in the year 2050 than the entire transport sector for the electrification scenario.

One of the main questions not considered in this research is how to satisfy all of the energy needs of the transport subsectors that are not viable for electrification. One of the logical assumptions would be to implement existing biofuels or emerging synthetic fuels [162]. The issue of biofuels in Croatia can be a sensitive one. The main issue is the actual potential of biofuels and their sustainability in Croatia. In future transport systems, the most difficult subsectors to model are the ones that are not likely to be electrified. For the purposes of this research, most of those subsectors are “transferred” to biofuels or synthetic fuels. Ultimately, the NeD model is scenario-based; thus, the transition rate to biofuels or synthetic fuels can be set by the user.

In Figure 36 biofuels comprise biodiesel, ethanol and biomethane. When the NeD model calculates the substitution of biofuels for fossil fuels, it compensates for the lower energy value of biofuels from one side, but it also takes into consideration higher specific consumption of biofuels. Unfortunately, when calculating the whole transport subsector, specific consumption cannot be imported into the model as an input data. It has to be calculated from known parameters for the reference year, such as vehicle fleet properties and total final energy consumed. The data shown in Table 10 is used just as guidance and a boundary condition in the process of calculating actual values, dependent on a certain fuel form in the reference year. As input data, the parameters from Table 14 are imported into the NeD model.

Table 14 Volumetric energy density of biofuels and their comparison to compatible fossil fuels

Diesel (MJ/l)	Biodiesel (MJ/l)	Gasoline (MJ/l)	Ethanol (MJ/l)
36	33	32	21

The introduction of synthetic fuel is most likely in the air transport subsector; however, it is also possible in other forms of transport.

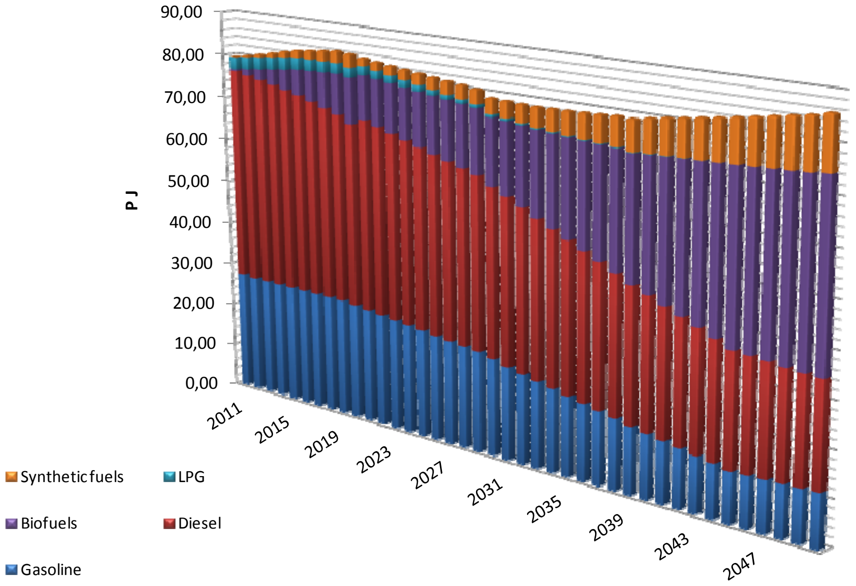


Figure 37 Fuel mix of the road transport subsector, without electrification – Reference scenario

3.1.3 Industry sector

The reference year was chosen to be 2011 due to the absence of economic disturbance with the objective to obtain valid data related to energy consumption and industrial production in average conditions.

The final energy consumption share of the industry sector is shown in Figure 38. The construction materials industry participates in total final energy consumption with a significant amount of 27.9%, followed by the food industry with 20.5%, chemical industry with 16.8 % and grouped – other manufacturing industries with 16.9%. All other industries, such as iron and steel industry, non-ferrous metals industry, non-metallic minerals industry and paper and pulp industry have a total share of 17.9% in the total final energy consumption of the industry sector. Industry specific issues are in most cases related to inefficient production due to obsolete equipment used in the production process together with industry specific energy sources. The downfall of Croatian industry is heavily influenced by the ongoing economic crisis in most sectors, apart from paper and pulp industry where a steady growth is noticed. Final energy consumption of the industry sector has fallen significantly when observing the amounts stated in 2010 in comparison with 2008. A downfall of 17.8% in final energy consumption has been noticed. Market conditions in combination with the weak financial situation and lack of solvency have caused a significant reduction of energy consumption in the majority of industrial sub-sectors.

As the construction sector came to a stagnation period around 2008, the unexpected market disturbance due to economic crisis caused a significant drop in the construction materials industry, which amounts to the downfall of final energy consumption in 2010 in comparison to the reference year. A similar, devastating effect has also happened in the non-ferrous metals industry where a downfall has been noticed.

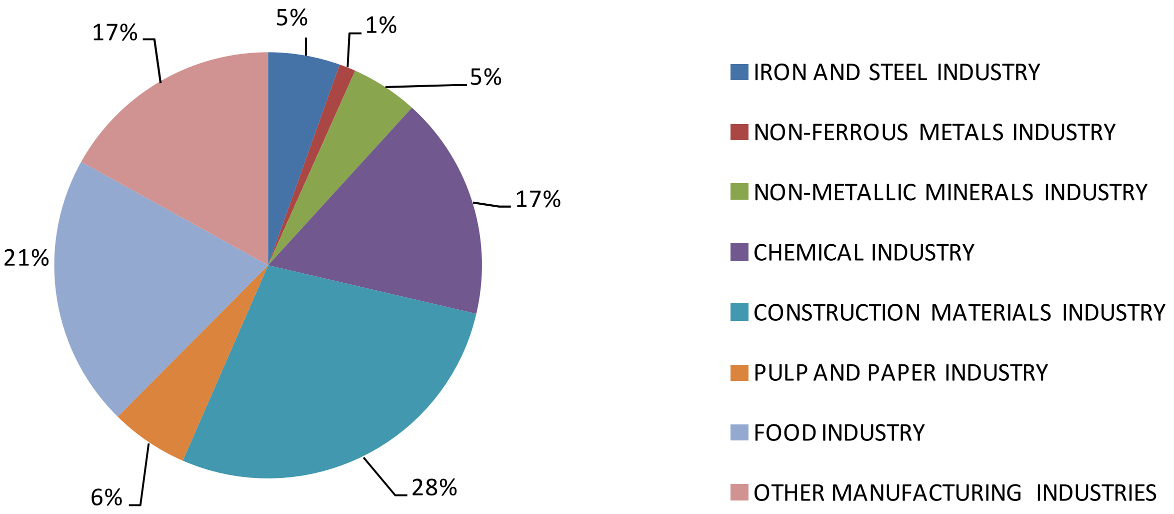


Figure 38 Final energy consumption share of the industry sector

Table 15 Final energy consumption in Croatian industry sector, 2008-2011

INDUSTRY SUB-SECTOR	**FINAL ENERGY DEMAND [PJ]**			
	2008	**2009**	**2010**	**2011**
IRON AND STEEL INDUSTRY	3.08	2.34	2.67	2.56
NON-FERROUS METALS INDUSTRY	0.60	0.55	0.47	0.59
NON-METALLIC MINERALS INDUSTRY	2.36	2.37	2.42	2.36
CHEMICAL INDUSTRY	10.23	9.18	8.55	7.92
CONSTRUCTION MATERIALS INDUSTRY	21.47	16.35	15.09	13.11
PULP AND PAPER INDUSTRY	2.72	2.77	3.04	2.77
FOOD INDUSTRY	11.80	9.46	9.95	9.67
OTHER MANUFACTURING INDUSTRIES	8.92	8.10	8.11	7.96
TOTAL INDUSTRY	**61.18**	**51.14**	**50.31**	**46.96**

3.1.3.1 Scenario analysis

Total energy demand of each industry is calculated according to assumptions by taking into account several possible outcomes, i.e. scenarios. An overview of variables for each scenario is presented in Table 16. Table 16 values are taken arbitrary and are determined to describe five specific scenarios; business as usual (continuation of current trends), decrease of current imports and intensified consumption (as a consequence of economic recovery), orientation to domestic production, RES oriented and export oriented. The first scenario is assumed to be 'business as usual' where current trends of slow growth or even slight decline are applied. The scenario envisages growth of imported goods by 15% by 2050 with a slight rise of consumption per capita, which amounts to 3% for each sub-sector of industry and 6% growth of export quantities. Also, final energy consumption is expected to drop by 4% by 2030 and further 6% by 2050 with implementation of energy efficiency measures in the industry sector. It has been envisaged that the utilisation of renewable energy sources will reduce the energy consumption by 7% by 2050.

Table 16 NeD model input parameters for respective scenarios and modelling up to 2050

Scenario	Scenario 1- Business as usual	Scenario 2 – Intensified consumption with the decrease of imports	Scenario 3 – Oriented to domestic production	Scenario 4 – RES oriented with increased consumption	Scenario 5 – Export oriented with increased consumption
Import change	15%	9%	-2%	-6 to 5%	-6 to 5%
Consumption per capita	3%	6%	6%	51%	36%
Export	6%	11%	17%	52%	36%
Energy efficiency	10%	10%	10%	10%	18%
Renewable energy sources	7%	9%	14%	32%	18%

Other scenarios have been obtained by changing variables to determine the sensitivity of the system, determine the influence of each variable and observing the possible outcome of all changes made to the model. For instance, the second scenario envisages smaller import growth (9% by 2050), also with the bigger growth of consumption per capita (6%) and bigger growth of exported goods (11% by 2050). Reduction of energy consumption due to the application of energy efficiency measures in this case remains the same as in the previously described scenario, but with slightly larger growth of energy produced from renewable energy sources (9% by 2050). Scenario 3 predicts a slight fall of import (2%) in the overall industry sector with an increase in quantities of exported goods of 17% by 2050. Reduction of energy consumption due to implementation of energy efficiency measures remains at the same level as in the previous two scenarios. The share of renewable energy sources is increased to 14% in this scenario. Scenarios 4 and 5 are significant because they present the situation in which the share of imported goods drops to 10% in overall product consumption. In these scenarios, such assumption will definitely have an impact on energy demand of the industry sector. To achieve an even bigger effect, consumption of goods per capita is also set to rise by 51% in Scenario 4 and 36% in Scenario 5. The main differences between these two scenarios are made in predicted increase rates of exported goods, which in the case of Scenario 4 amounts to 52% and in the case of Scenario 5 to 36%. Also, a difference has been made in the implementation of energy efficiency measures between Scenario 4 and Scenario 5, 10% and 18%, respectively, and the implementation of renewable energy sources, 32% and 18%, respectively.

It must be noted that all modelled scenarios yield results in which the recovery of the industry sector, visible from final energy demand in Scenarios 3, 4 and 5, happens at around 2020. On the other hand, Scenarios 1 and 2 point out that the complete recovery may not occur. Such outcome is highly probable, especially with the implementation of subsidies for energy efficiency measures and renewable energy sources in the industry and many breakthrough technologies becoming economically viable. Many other relevant factors will influence and shape the future final energy demand of the Croatian industry sector.

3.1.3.1.1 Energy produced from Renewable Energy Sources

Apart from energy efficiency measures, renewable energy sources as per the inputs defined in respective scenarios have high impact on final energy demand of Croatian industry sector. The amounts of energy obtained from utilization of renewable energy sources are presented in Figure 39.

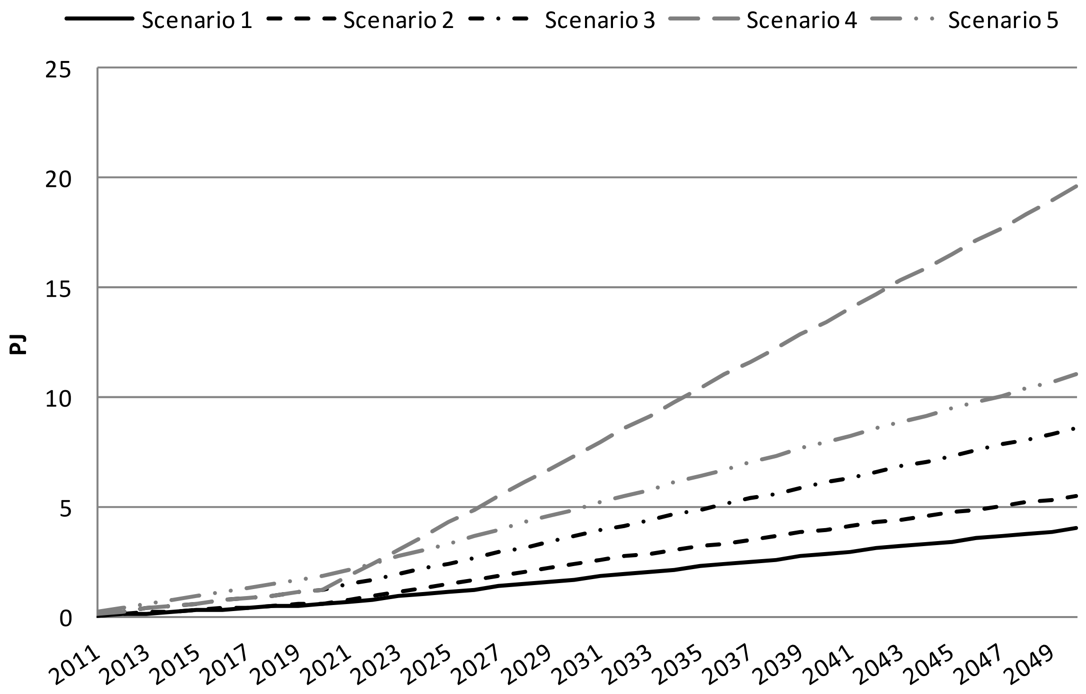


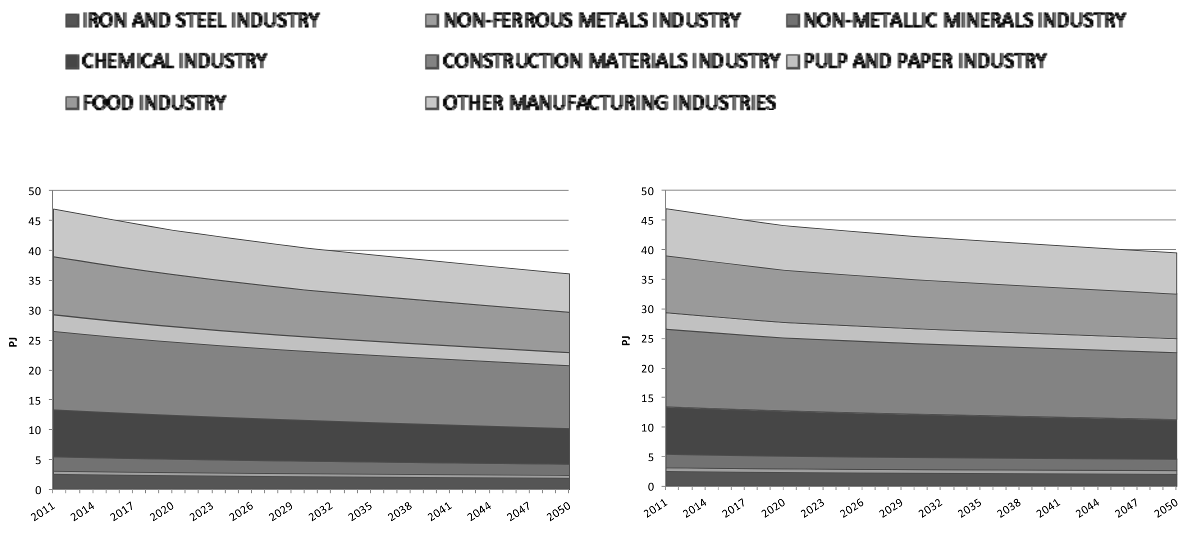
Figure 39 Energy gained from utilization of renewable energy sources in modelled scenarios

Expected price growth of fossil fuels and electricity will surely impact the day-to-day operation of the industry. As proven from numerous cases across the world, regardless of the sector or activity, renewable energy sources can provide financial and energy savings if properly combined and synchronized with implementation of energy efficiency measures. In most cases, energy "weak spots" are easily spotted in an industrial plant and large savings can be achieved by a simple replacement of old components and elements. Exploitation of renewable energy sources, wherever possible and economically viable, should further enhance the impact of the implemented energy efficiency measures and highly influence the industry costs to provide a sufficient boost for recovery of the industry. The gradual recovery of the industry sector, as predicted in Scenarios 3, 4 and 5 will be highly influenced by energy efficiency measures and implementation of renewable energy sources to cover the majority of the rise in energy consumption. The actual amount of energy produced with renewable energy sources has been calculated based on the input data and previously calculated final energy demand for each year by supplementing each fuel type in the respective industry.

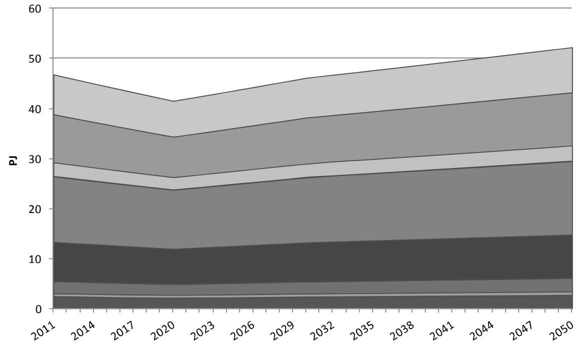
3.1.3.1.2 Final energy demand projection up to 2050

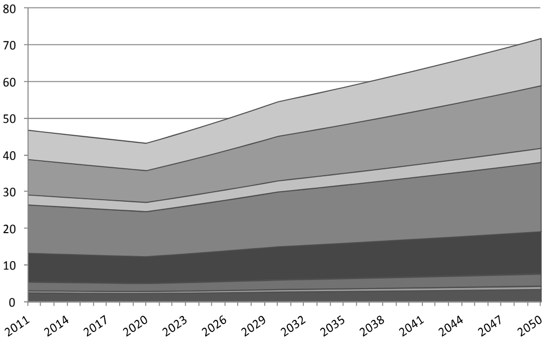
Final energy projection up to 2050 is shown in Figure 40. The final energy demand in modelled Scenario 1 shows a total industry energy demand downfall where the leading industries - Food, Chemical and Construction materials have the sharpest decline. As expected, some types of industries will gradually phase out, but such occurrence has not been taken into consideration in the taken period from 2008 – 2050. The final energy demand in Scenario 1 is 36.12 PJ in 2050, which displays a downfall of final energy demand of 23% in comparison to 2011.

Scenario 2 also shows a downfall in energy demand, however a smaller one than in the case of Scenario 1 due to smaller input values of import quantities change and larger quantities in export. The final energy demand in Scenario 2 is larger than in Scenario 1 and is 39.6 PJ in 2050.

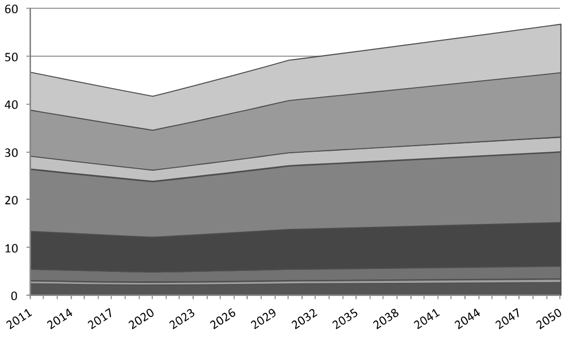


Scenario 1. Scenario 2.





Scenario 3. Scenario 4.



Scenario 5.

Figure 40 Final energy demand projection in IED scenarios

Scenario 3 contains a steady decrease in import quantities and increase in export quantities, meaning an increase in domestic production and consequentially increase in final energy demand to 52.19 PJ in 2050. The implementation of energy efficiency measures as envisaged in the scenario is not enough to keep the final energy demand on a steady level without an increase in final energy demand.

Scenarios 4 and 5 have varying value of import change (from -6 to 5%) but in comparison to Scenarios 1, 2 and 3 they have large increases in product consumption per capita and export quantities. Energy efficiency measures have a bigger impact in Scenario 5 compared to Scenario 4. The final energy demand of Scenarios 4 and 5 are 71.85 PJ and 56.86 PJ respectively.

3.1.3.1.3 Final energy mix in modelled scenarios

3.1.3.1.3.1 EUROSTAT methodology

Since fossil fuels are still the main energy source it is interesting to provide information on how the energy mix in the modelled scenarios will change. Depending on the input parameters related to energy efficiency, but also parameters which determine the overall energy demand of the industry, the contribution of renewable energy sources will cover up to 25% of the final energy mix depending on the scenario as shown in Figure 41.

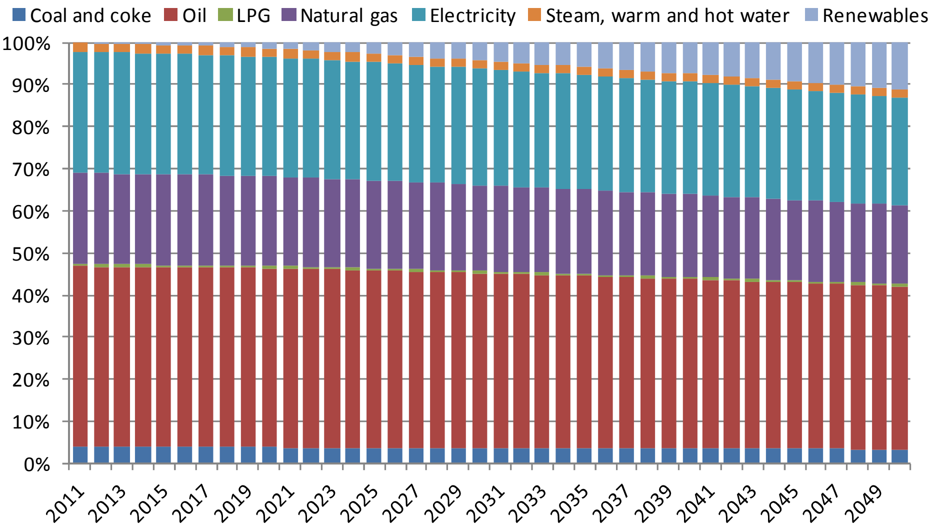


Figure 41 Final energy fuel mix in Scenario 1

Figure 41 displays the fuel mix in the case of Scenario 1 in which, according to inputs, electricity has the largest decline due to the production of electricity from renewable energy sources. Also, a decline in oil and natural gas can be noticed in 2050 since it has been considered that the processes which generate heat from these fuels will be replaced with renewable energy sources or upgraded with heat recovery systems. Final energy fuel mix in Scenario 2 is shown in Figure 42.

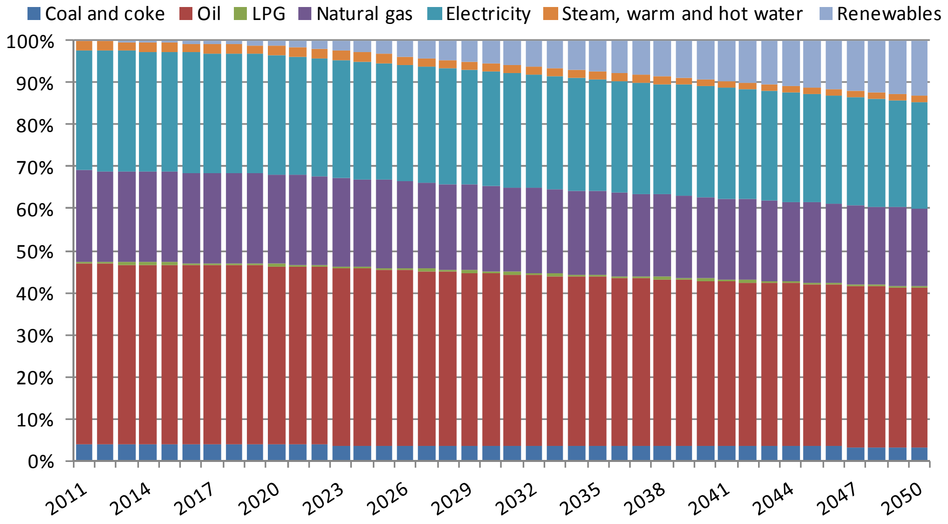


Figure 42 Final energy fuel mix in Scenario 2

Scenario 2 has slightly higher final energy demand in comparison to Scenario 1 but due to changed input parameters also a bigger contribution of renewable energy sources in the final energy mix. A significant reduction in oil consumption and natural gas can be noticed. Also, a decrease in electricity consumption is visible since renewable energy sources are envisaged to contribute to electricity production. Fuel mix for Scenario 3 is shown in Figure 43.

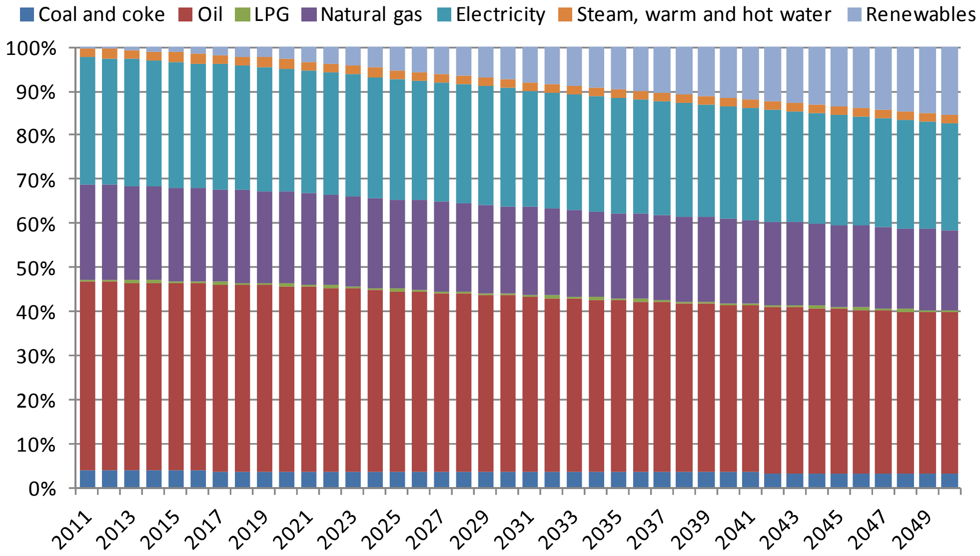


Figure 43 Final energy fuel mix in Scenario 3

The fuel mix in Scenario 3 shows an increase in the share of renewable energy sources in the final energy mix in comparison to Scenarios 1 and 2 as determined by the input parameters with a simultaneous decrease in oil, natural gas and electricity consumption. Figure 44 and Figure 45 present the final energy fuel mix for Scenarios 4 and 5.

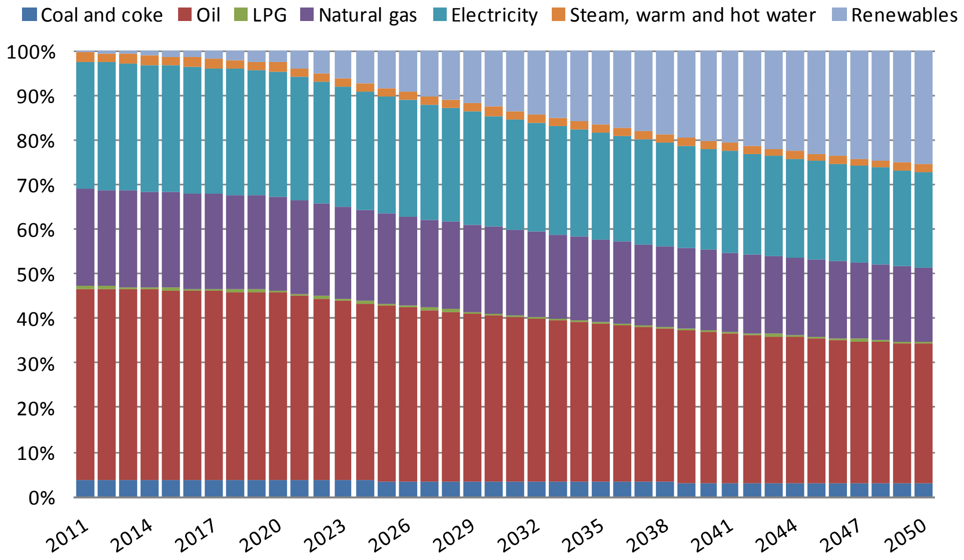


Figure 44 Final energy fuel mix in Scenario 4

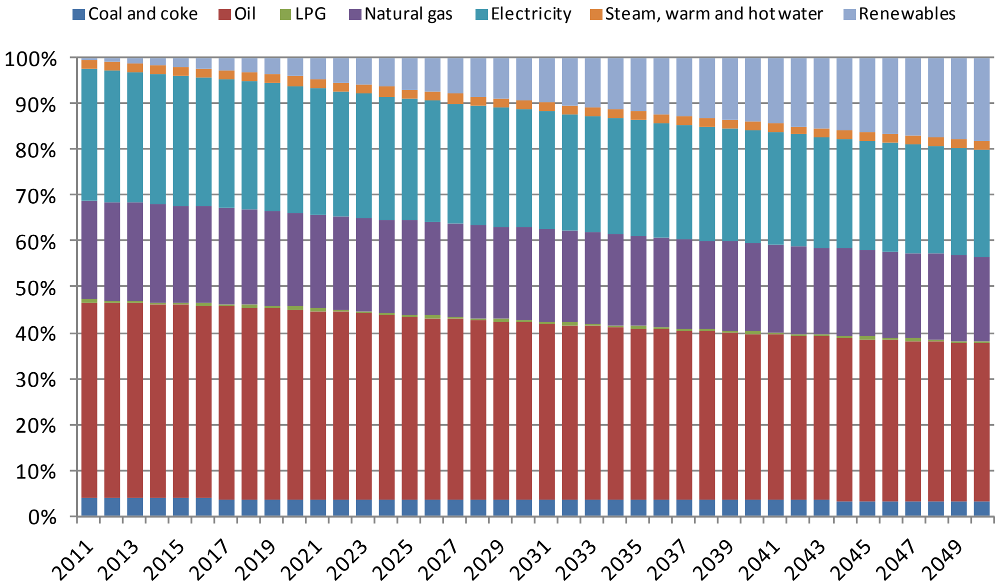


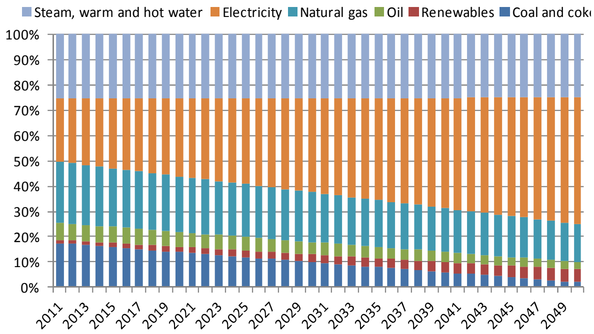
Figure 45 Final energy fuel mix in Scenario 5

The largest decline in fossil fuel consumption in Scenarios 4 and 5 is expected where the largest growth rates of renewable energy sources are set. Scenarios 4 and 5 have also shown that energy efficiency and renewable sources will play a very important role in the phase of Croatian industry development. If compared with other three scenarios (1, 2 and 3) these scenarios show that the rapid growth expected in the future periods can only be supported by strong energy efficiency and renewable energy sources measures. In this sense, the policies related to both will have to be properly suited to facilitate the growth and further development.

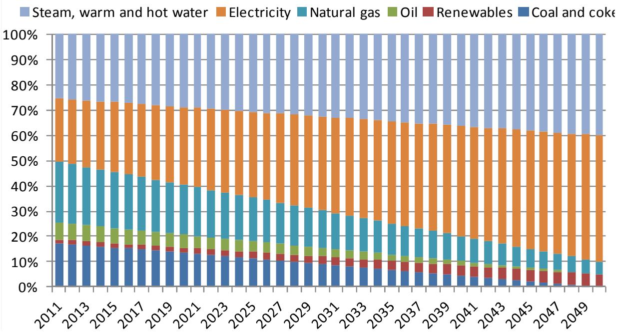
3.1.3.1.3.2 Croatian energy balance fuel mix

Fuel mix results for five modelled scenarios in Chapter 3.1.3.1.3.1 have been made based on the EUROSTAT methodology. This was done because, based on the EUROSTAT methodology, reference fuel mix in 2011 was available for various industry sub-sectors. Unfortunately EUROSTAT industry fuel mix in Croatia does not correlate to the national energy balance for the industry sector. This discrepancy is in different methodologies used in the industry sub-sector division and various energy transformation variables. Croatian national energy balance allows only total fuel mix for the whole industry sector.

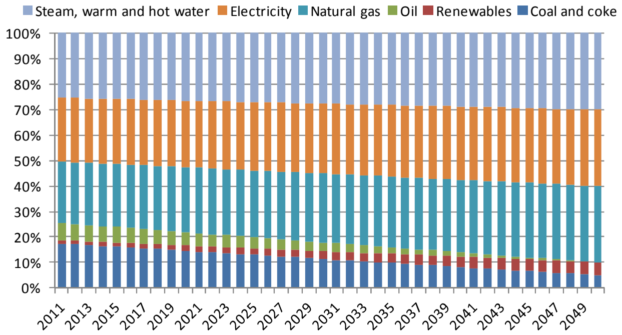
Since the reference year and fuel mix of this research is based on Croatian energy balance, the author has created an additional fuel mix mode to follow Croatian national energy balance fuel mix on an aggregated level. The results of all five scenarios are presented in Figure 46.



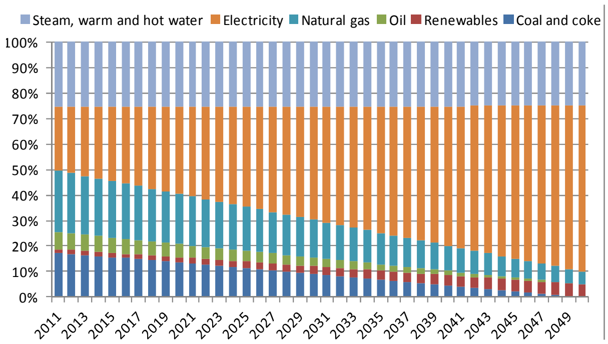
Scenario 1.



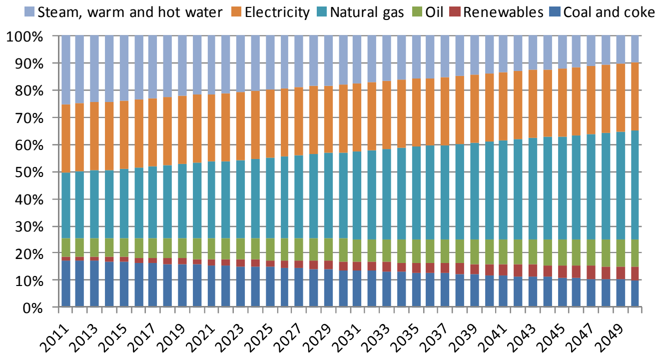
Scenario 2.



Scenario 3.



Scenario 4.



Scenario 5.

Figure 46 Fuel mix by Croatian energy balance

3.1.4 Services sector

3.1.4.1 Scenario analysis

Four different scenarios of the Croatian services sector can be seen in Figure 47. The first scenario was the reference one, while the following three represented three different yearly renovation rates of available floor surfaces (EE1 (1%), EE2 (2%) and EE3 (3%) scenario). The reference scenario uses the same assumptions and input data used in the households sector, as described in Chapter 3.1.1. If the two most extreme scenarios, the reference and the 3% renovation rate are compared, energy demand in the year 2050 could be 26% lower. The renovation rate was directly connected to the EU Directive 2012/27/EU on energy efficiency, which clearly states the yearly renovation rates for public buildings. Although fuel mix could have been considered as supply side energy planning, the NeD model had the possibility of transferring the useful energy demand into the final energy demand by introducing different technologies and their efficiencies. This is a very important feature of the NeD model because modelling long term useful energy demand allows influencing mechanisms that relate to building physics (insulation, building materials, building codes, yearly renovation rates, etc.) to be quantified. The second step (transition from useful to final energy demand) allows various technologies, fuel switches, technology efficiencies, etc. to be modelled. In Figure 47 all four scenarios are represented with the following fuel mix ratio for space heating purposes in the year 2050: 60% heat pumps, 20% district heating and 20% biomass.

In this “electrification scenario” all services subsectors are decreasing, except the tourism and catering trade sector (Figure 49). In the tourism and catering trade sector, the model presumes an increase in the available floor area (specific floor area per capita), which is not suppressed by the decrease of population. In all other services subsectors, the decrease in population, together with energy policy improvements (energy efficiency of technology and building physics) will lead to a long term decrease in the final energy demand.

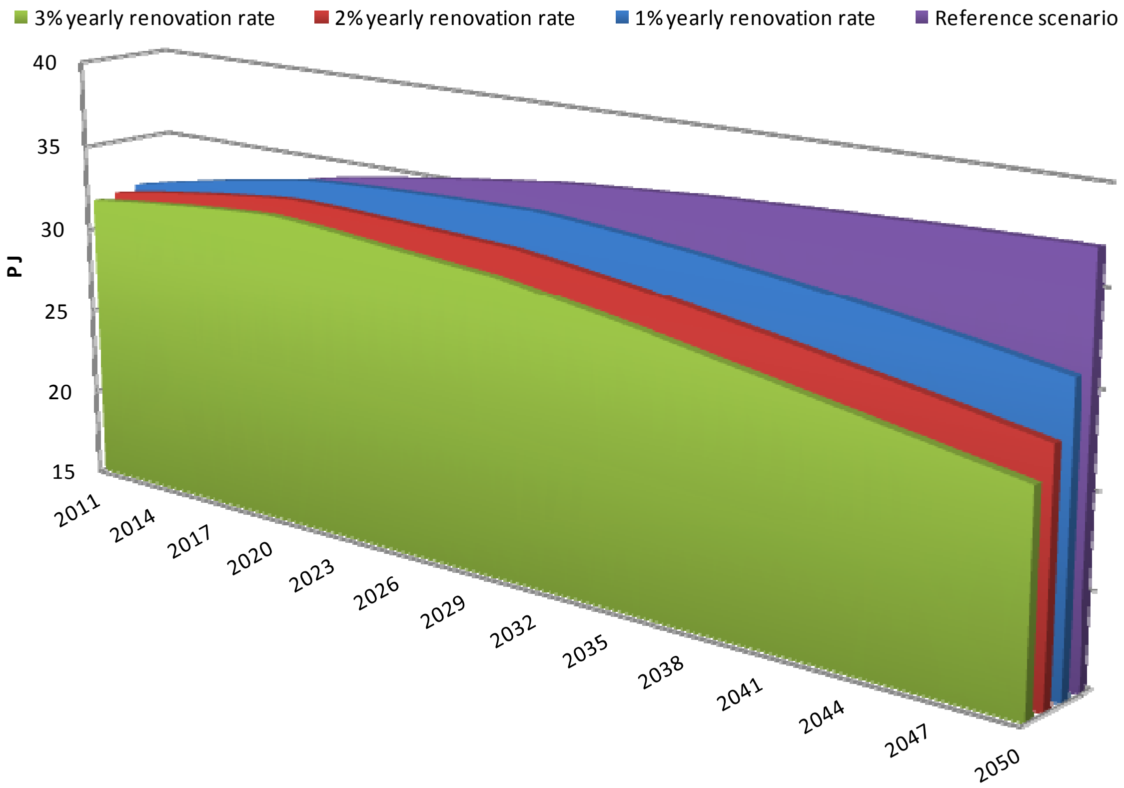


Figure 47 Long term energy demand scenarios of Croatian services sector

If analysing the 3% yearly renovation scenario of the services sector further, one of the most interesting results was the fuel mix (Figure 48). As could be expected, electricity had the steepest long term increase with almost 70% in the final energy demand in the year 2050. This was in line with the "all electrification trend". All services subsectors tended to increase the level of electrical appliance and devices. And with the introduction of heat pumps as space heating/cooling solution, increase in ratio of electricity in the services sector was expected. Liquid fuels were expected to have a total phase out until the year 2050, while gas fuels would have had an insignificant share in the same year.

As an alternative to gas and liquid fuels, electricity, biomass and district heating would have been heavily introduced. This was in line with the EU Directives on energy efficiency and RES which were especially favourable towards district heating/cooling. Lower temperature district heating was expected, with a higher share of renewable energy sources and waste heat.

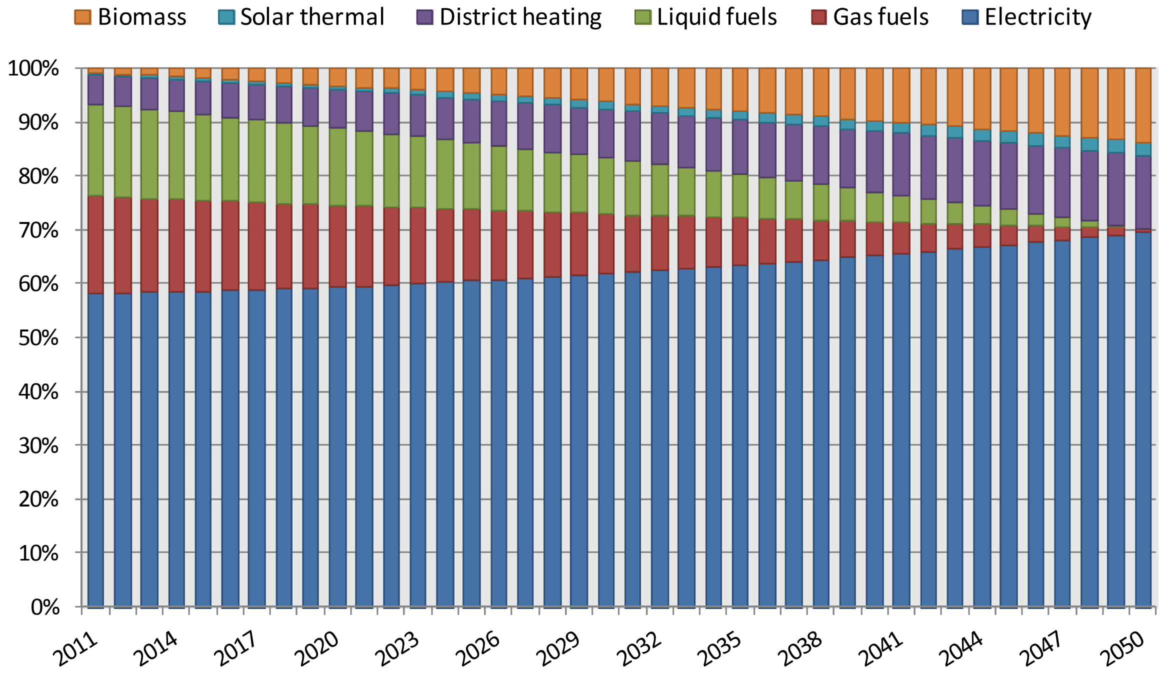


Figure 48 Fuel mix for Croatian services sector

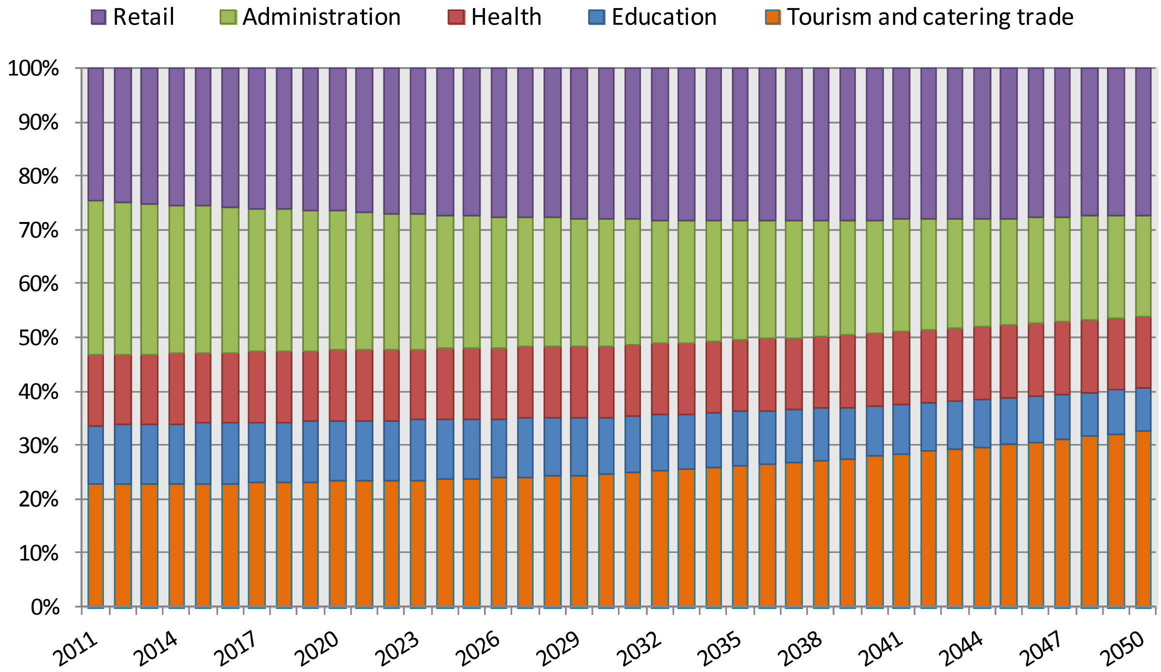


Figure 49 Services subsector distribution till 2050

3.1.5 Agriculture sector

3.1.5.1 Scenario analysis

Although agriculture, as well as the construction sector, were not so relevant when comparing it to the total national final energy demand they were still interesting to analyse. Agriculture represents 6% of the Croatian GDP[16]. It is important for the Croatian economy and society in general because 47.6% of the Croatian population is classified as rural[17]. Agriculture final energy demand model was scenario based. One of the main assumptions was the expected increase of the tertiary sector, which would directly cause the increase in the agricultural sector. This was combined with excellent agriculture potentials that were being unused in the last 20 years. With Croatia entering the EU, market for Croatian agricultural products has become much bigger. One of the key elements in the future agricultural production will be the efficiency of the agricultural process itself. From one side increase in energy efficiency of the machinery is important, but from the other side land concentration will play a key role in increasing future agricultural production. Currently agricultural production in Croatia is characterized by many small estates. Their cultivation presents a large dissipation of energy (Figure 50). For that reason the reference scenario has assumed an increase in agricultural production due to the country's strategic direction. Two main mechanisms regarding energy efficiency have been applied in this version of the NeD model. The one being land concentration scenario and the other being energy efficiency improvements of agricultural machinery scenario. Due to land concentration final energy demand could be decreased by 5.2% in the year 2050. Additional 7% decrease in final energy demand could be achieved by implementing energy efficiency improvements in the segment of agricultural machinery.

---

[16] EUROSTAT, Croatiastocar, Branko Bobetić

[17] OECD Methodology

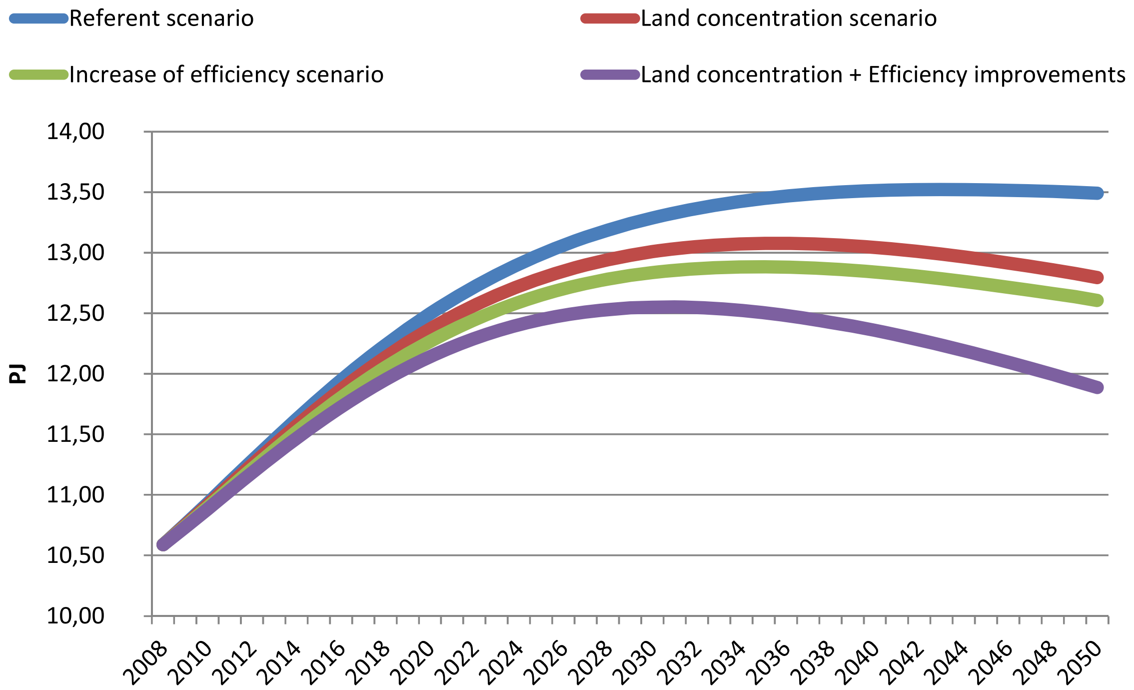


Figure 50 Long term energy demand scenarios of Croatian agricultural sector

3.1.6 Construction sector

One of the energy efficiency scenarios of the construction sector can be seen in Figure 51. Unfortunately, due to the specifics of the work required and technologies available, which were closely connected to heavy machinery, this sector was expected to stay heavily dependent on liquid fossil fuel. One of the possibilities was a graduate switch to biofuels, which could be expected in the future as well as a gradual introduction of synthetic fuels. The gradual switch towards biofuels was expected based on the renewable energy sources Directive, which prescribes required biofuel share in the transport sector. In all categories 5% increase in energy efficiency was assumed until the year 2050 in [GJ/m^2] or [GJ/construction site]. This figure was arbitrary, but it reflected current EU efforts towards energy efficiency improvements in all sectors.

For all the specific energy demand categories 50% increase until 2050 has been assumed [m^2/capita] and [building permits/capita]. Although a significant increase for the specific energy demand categories has been assumed, overall final energy demand has a continuous upraise until the year 2050, but reaching the pre economic crisis level (year 2008) only in 2035. The first reason for this was the expected increase in energy efficiency while the second reason was a steady decrease of population in Croatia until the year 2050.

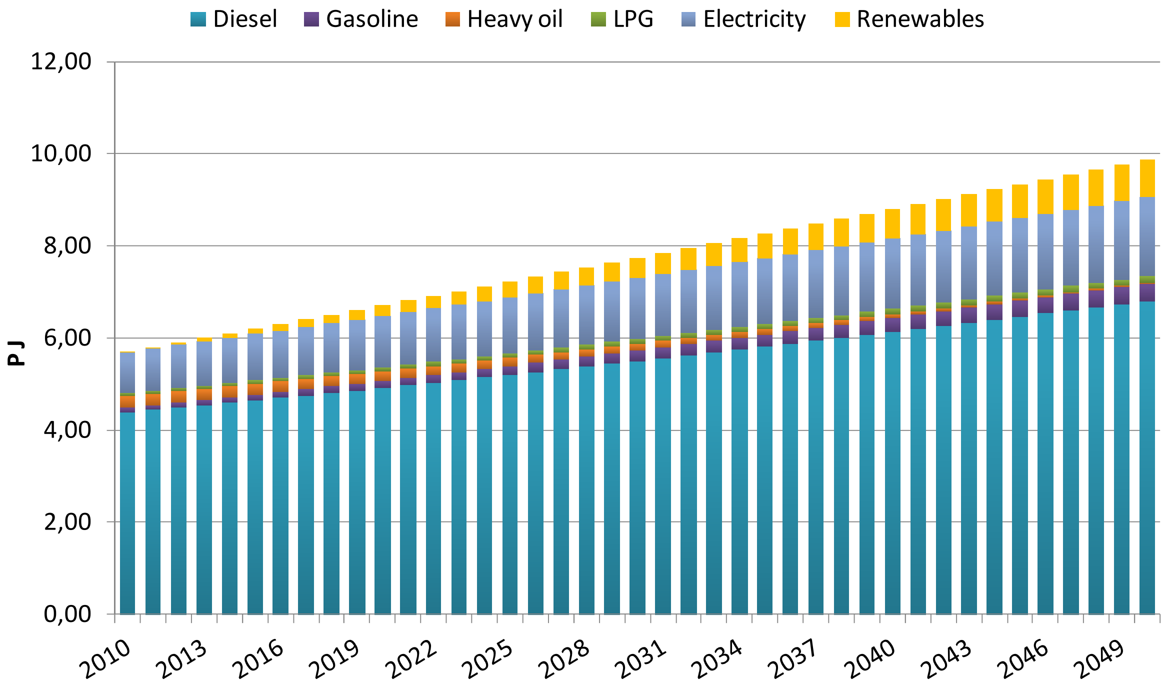


Figure 51 Long term energy demand of Croatian construction sector – Reference scenario

3.1.7 Wedge approach

One of the key features of the NeD model was to show energy efficiency wedges for all sectors and at the end for the whole country. In Figure 52 energy wedges of the Croatian households sector, calculated with the NeD model are shown. The difference between the two most extreme scenarios (LowE and EE3 scenario) is 38.7 PJ. If we exclude energy efficiency policy, final energy consumption of the Croatian households sector would increase from 79.5 PJ in 2011 to 94 PJ in 2050. This is due to the increase of living space per capita due to the increase of standard, described in Chapter 3.1.1. With the implementation of 1% yearly renovation rate energy consumption in 2050 can be reduced by 8.2%. Further implementation of energy efficiency policy and increasing the yearly renovation to 2% together with high intake of biomass can additionally reduce the energy consumption in the year 2050 by 18.5%. If we substitute individual biomass with district heating, an additional 3% in the year 2050 could be saved. Finally, increasing the yearly renovation rate to 3% and switching to heat pumps could reduce final energy demand in the year 2050 by an additional 11.5%.

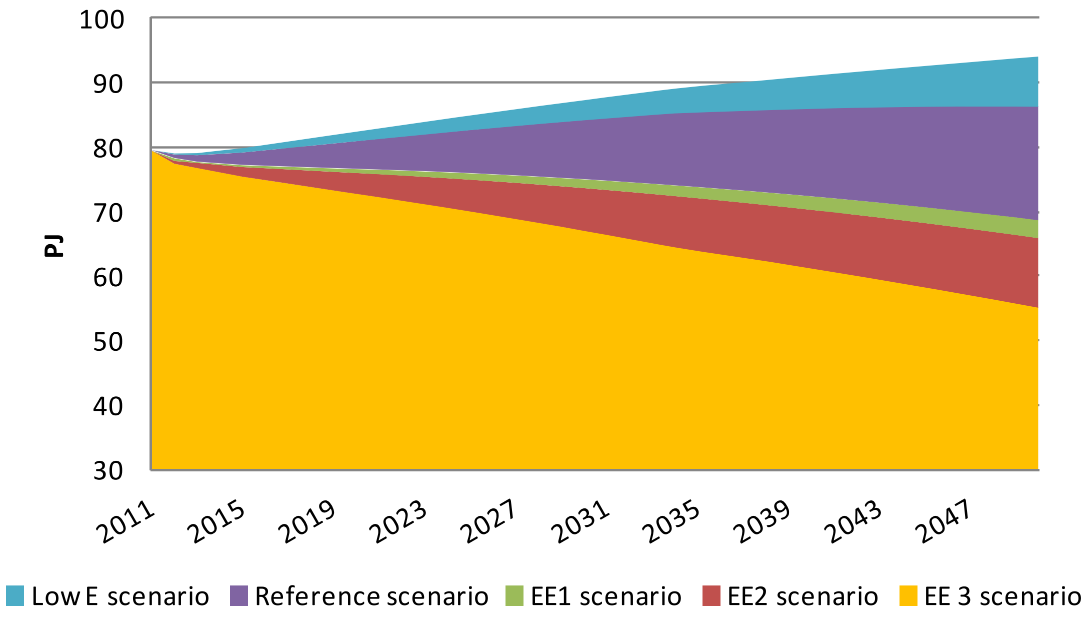


Figure 52 NeD Croatian households sector wedges

In Figure 53 energy wedges of the Croatian transport sector are shown. The difference between the two extreme scenarios (Frozen efficiency and EE3 scenario) is 92.2 PJ. If we neglect energy efficiency improvements of the Croatian transport sector, energy consumption in 2050 would reach 148 PJ. This presents a 75% increase in comparison to 2011. This is mostly the result of 50% increase in specific car number, as explained in Chapter 3.1.2. If expected energy efficiency measures are implemented (following Primes EU28) energy demand in 2050 could be reduced by 34.7%. Additional efforts on increasing energy efficiency of internal combustion engines could bring additional 8% savings in the year 2050. Electrification of personal vehicle fleet in 2050 could decrease the final energy demand for an additional 13.4%. Finally by introducing modal split between road, air and rail transport the final energy demand in the year 2050 could be reduced by an additional 6%.

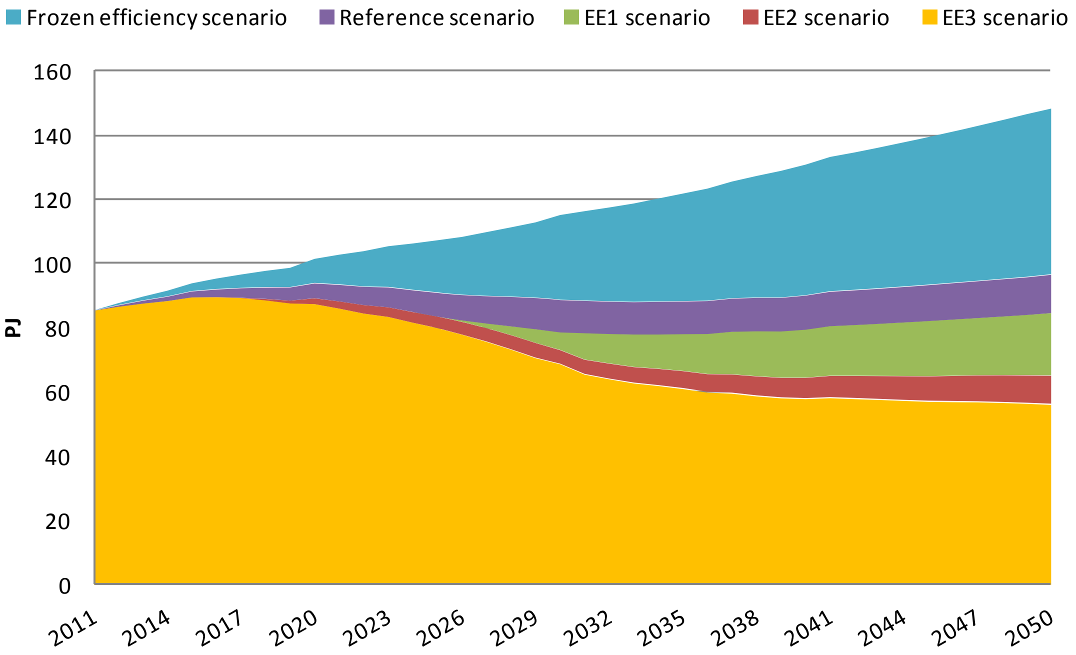


Figure 53 NeD Croatian transport sector wedges

In Figure 54 energy wedges of the Croatian industry sector are shown. The difference between the two most extreme scenarios (SC1-Business as usual and SC4-RES oriented scenario with increased consumption) is 35.73 PJ. Specific input parameters of each scenario are given in Table 16. If comparing the SC4 scenario (RES oriented with increased consumption) with the SC5 scenario (export oriented) possible decrease in energy consumption in 2050 could be 21%. Additional 7% decrease can be expected if the SC3 scenario (oriented to domestic production) is applied. Finally, a 18% decrease, compared to the SC4 scenario, can be achieved by decreasing imports of industrial goods and turning to domestic production with the SC2 scenario.

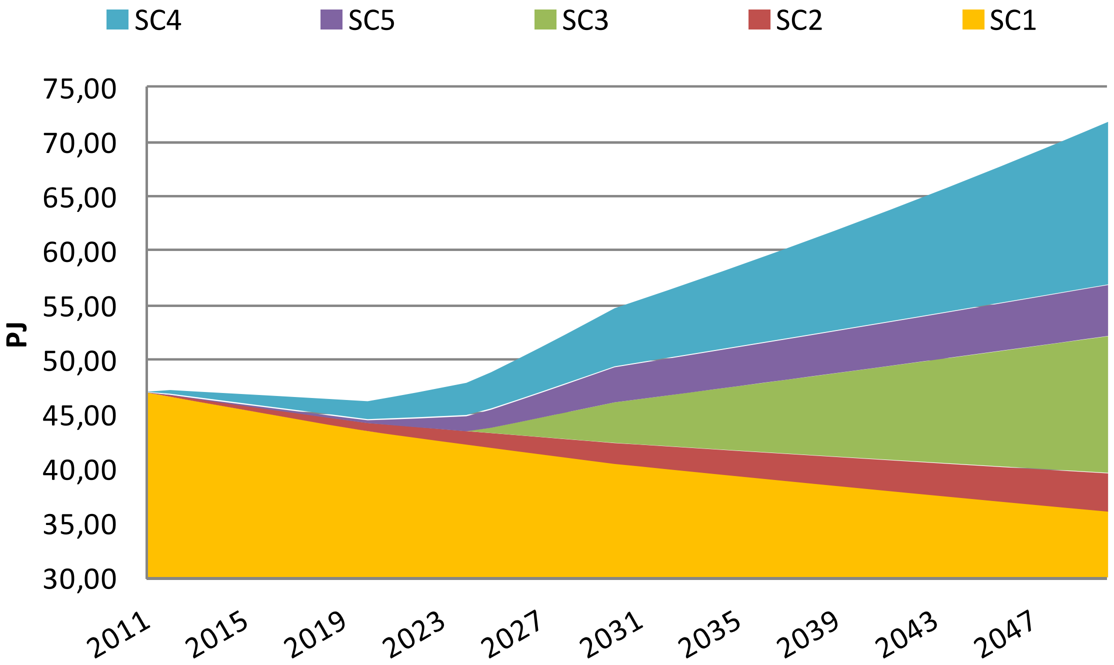


Figure 54 NeD Croatian industry sector wedges

In Figure 55 energy wedges for the Croatian services sector are shown. The scenarios correlate to the households scenarios and include the same assumptions. Different yearly renovation rates are assumed, as well as energy efficiency improvements and three main technology pathways (biomass in EE1 scenario, district heating in EE2 scenario and heat pumps in EE3 scenario). The difference between the two most extreme scenarios (Reference and EE3 scenario) is 9.7 PJ. Based on the energy policy implementation, possible energy savings are 14.1% with EE1, 7.5% with EE2 and 4.4% with EE3 in the year 2050.

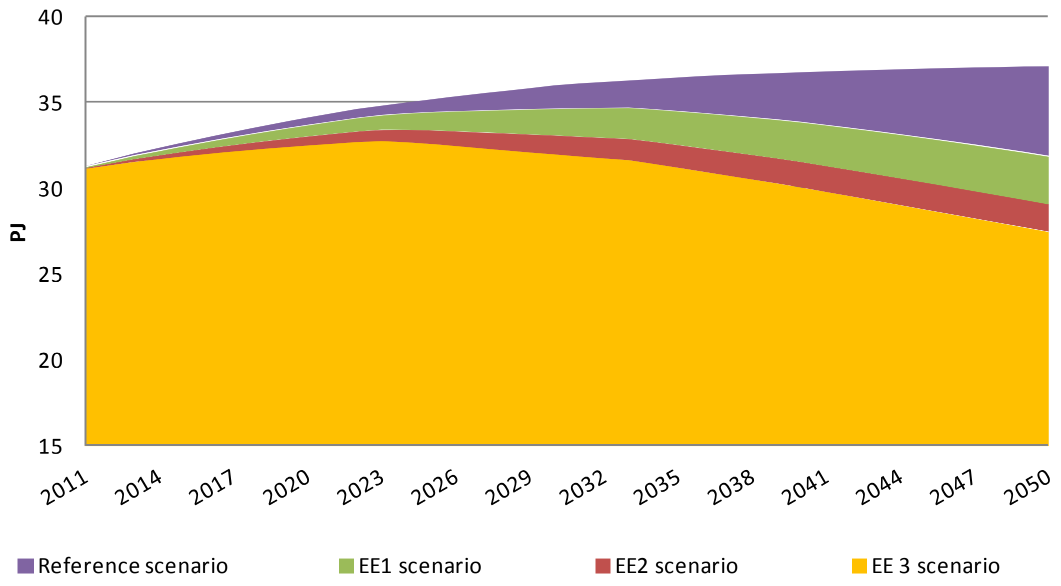


Figure 55 NeD Croatian services sector wedges

Finally, potential energy wedges for the whole Croatia are shown in Figure 56. In order to maintain a relatively clear figure only three main sectors and 12 energy wedges are presented. For the other three sectors, their reference scenarios are used. First four wedges in Figure 56 refer to four major transport energy policies, as explained in Chapter 3.1.2. Next four wedges refer to industry as explained in Chapter 3.1.3. Final four wedges refer to households, as explained in Chapter 3.1.1. The analysis has shown that the potential energy savings could go up to 166.7 PJ in the year 2050, which would present a 46% decrease in energy consumption if compared to the frozen energy efficiency scenario. Based on the set parameters, explained in Chapter 3.1.2, the transport sector has the biggest potential in energy efficiency improvements. Final energy demand of Croatia in the year 2050 with frozen efficiency would go up to 363.6 PJ (dark blue surface in Figure 56), while with the implementation of various energy policies in three main economic sectors the energy consumption could drop below 200 PJ, to 196.9 PJ (yellow surface in Figure 56).

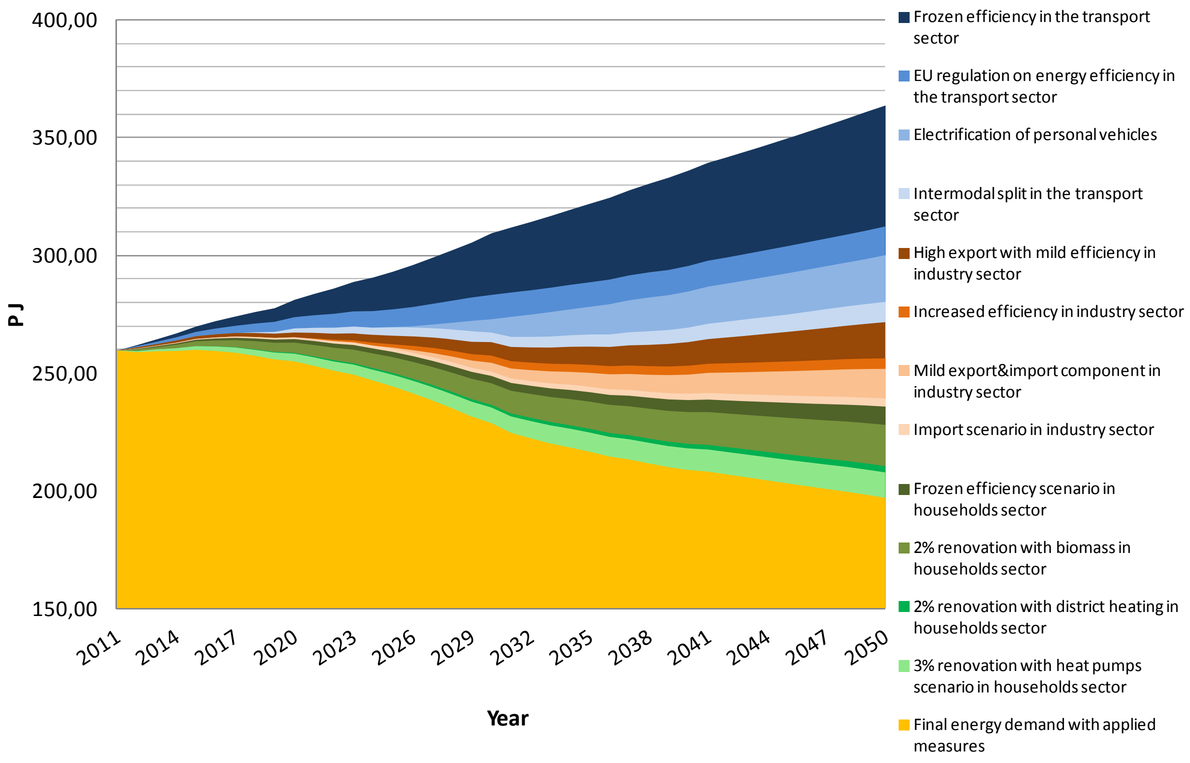


Figure 56 NeD Croatian national wedges

The energy demand scenario coloured in yellow in Figure 56 (Final energy demand with applied measures) is presented in a more detailed way in Figure 57 and Figure 58. As expected main energy savings were achieved in the households and transport sector (Figure 58). In Figure 57 a significant increase in electricity demand can be seen, especially in the 2030s when the electrification of personal vehicles will start heavily. Beside electricity, the only two fuels where an increase is expected are renewable energy sources and heat, through district heating. A 40% increase of electricity demand is expected in the year 2050, if compared to the reference year, from 56.58 PJ to 79 PJ. But at the same time, a 24% decrease of final energy demand is expected in the year 2050, if compared to the reference year. A significant decrease in liquid fuels and gaseous fuels is expected in 2050 as well. Liquid fuels will decrease by 66%, while gaseous fuels will decrease 76% by 2050, if compared to the reference year. This is in line with the long term energy policy of the EU, which strives towards decarbonised society in the year 2050 and drastic reduction of CO_2 emissions. In the following Chapter 3.1.8 a long term EU goal regarding CO_2 emission reduction will be shown.

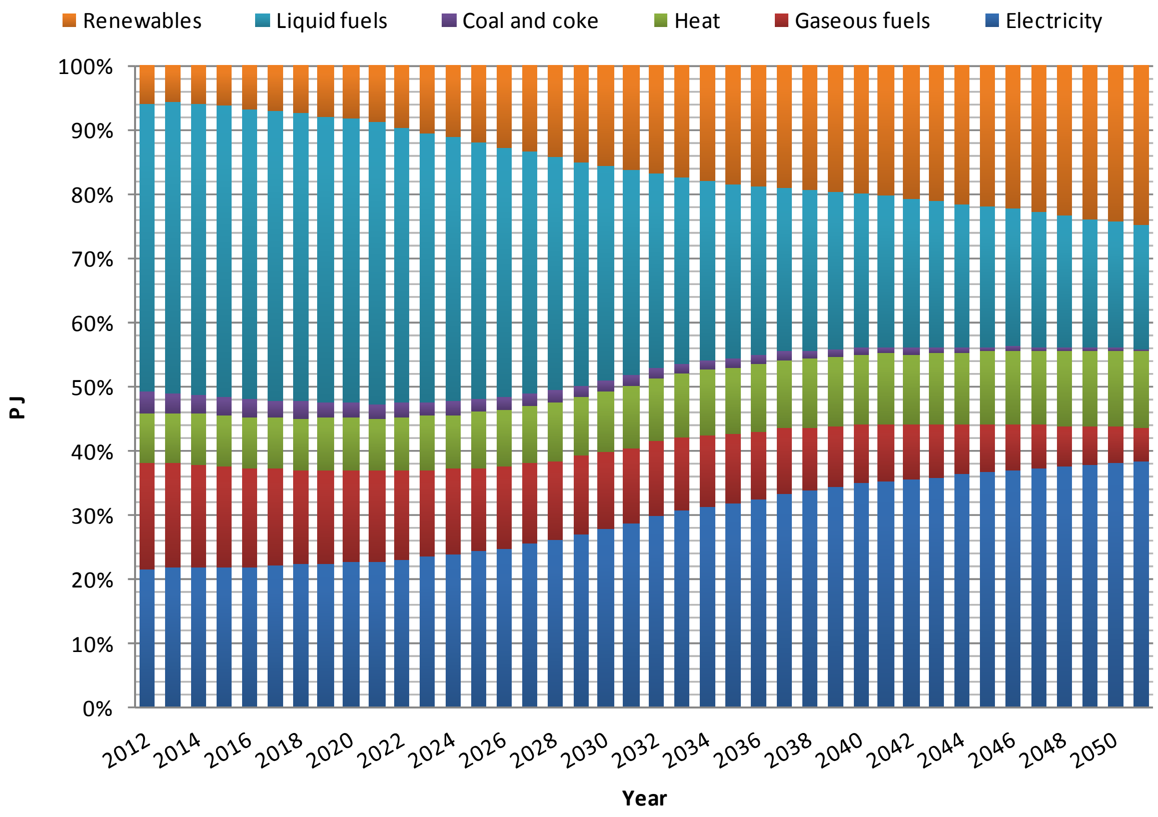


Figure 57 Fuel mix of Croatian final energy demand after measures of energy policy have been implemented

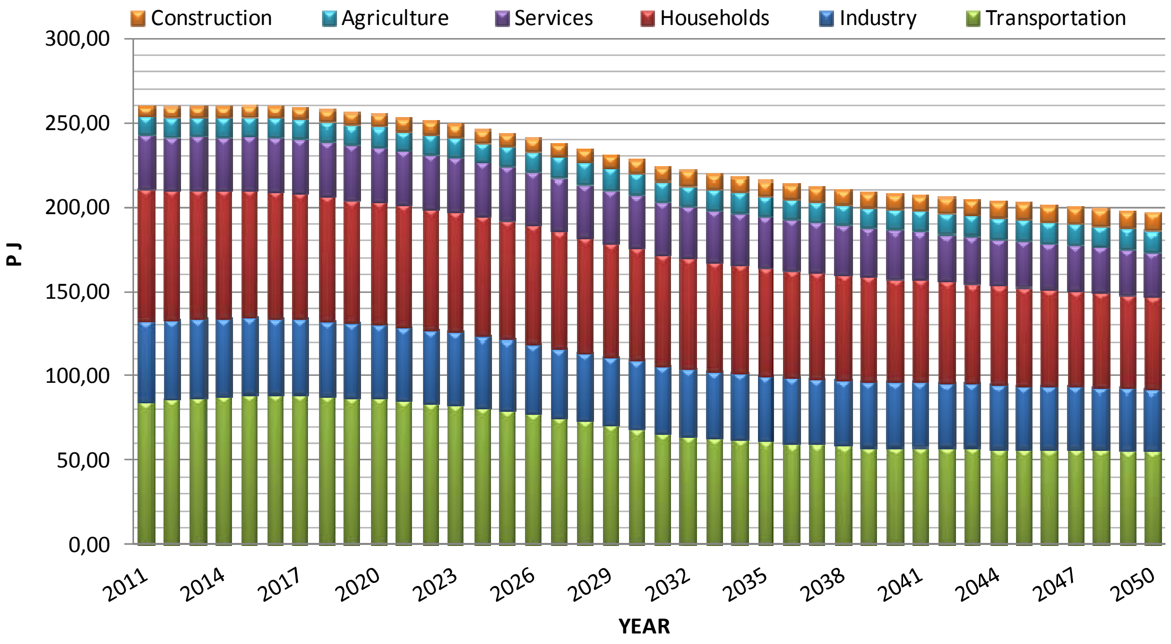


Figure 58 Croatian final energy demand after measures of energy policy have been implemented – by sector

3.1.8 Green house gas emission mitigation

After all the sectoral energy demands and fuel mixes were calculated they were imported into the GHG mode, which was used for calculating CO_2 emissions for every energy demand scenario.

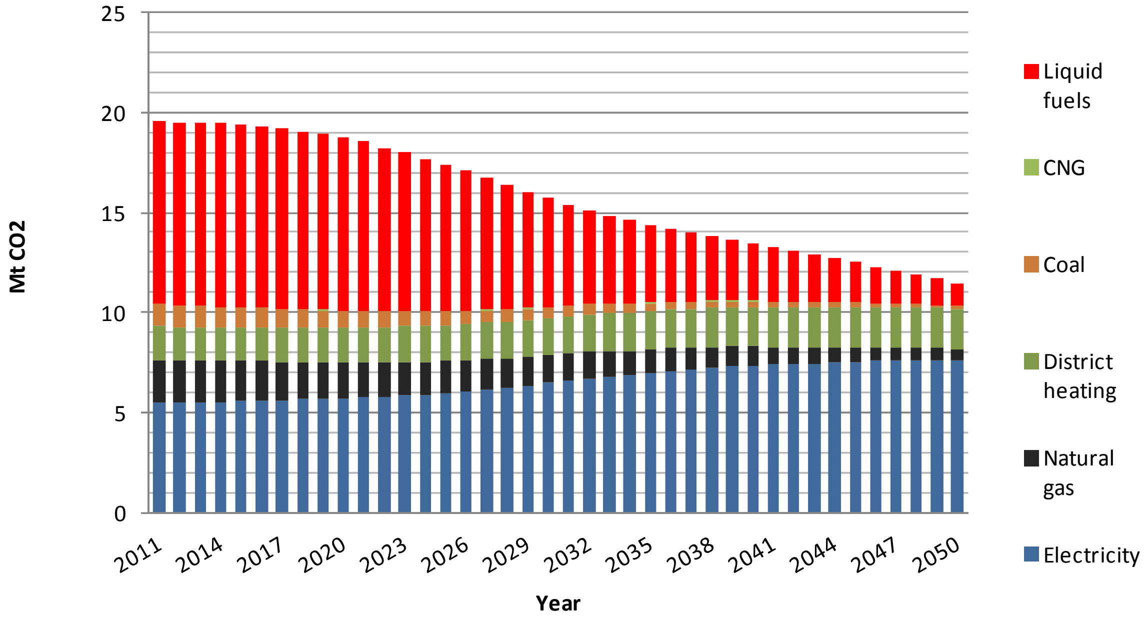


Figure 59 CO_2 emissions of the energy efficiency scenario calculated with the NeD model

Based on the high intake of renewables through most of the sectors which was followed by a high electrification process, also through most of the sectors, CO_2 emission could be reduced substantially until the year 2050. If comparing the years 2011 and 2050, significant CO_2 reductions could be achieved with careful and rational energy demand planning. The NeD model calculated 41% lower CO_2 emission in the year 2050 if compared to 2011. The scenario in Figure 59 was calculated by the same national electricity to CO_2 conversion factor valid in 2011, which is not realistic. The same approach was used to calculate the GHG emissions from district heating. Until the year 2050 it is expected for the electricity generation and district heating sectors to be more CO_2 free than today.

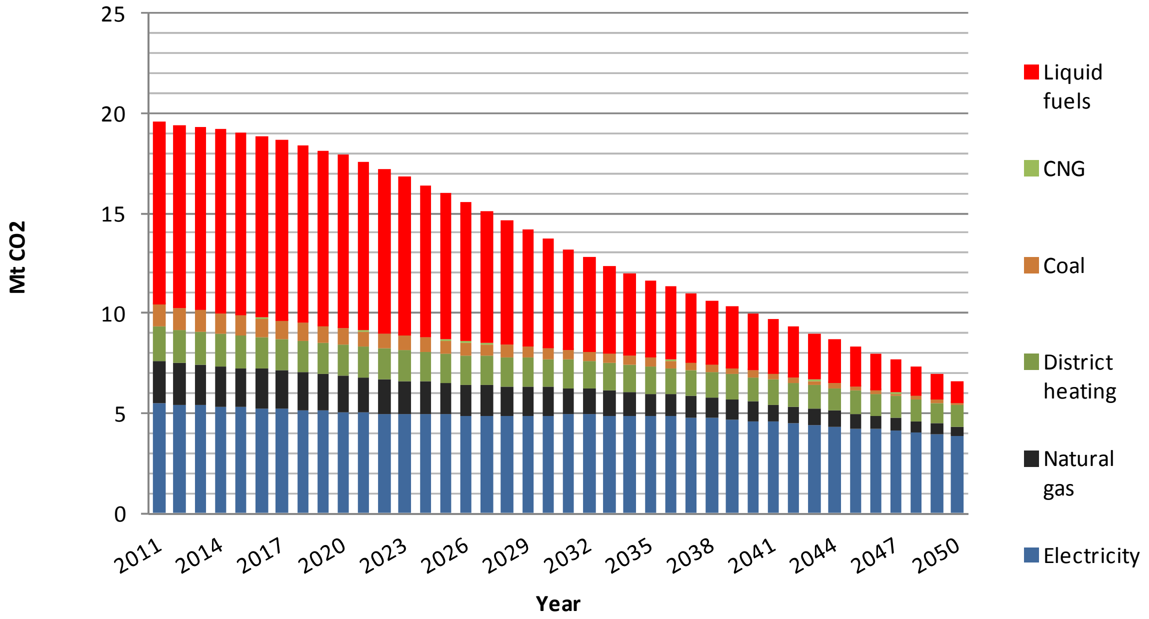


Figure 60 CO_2 emissions of the energy efficiency scenario calculated with the NeD model with electricity conversion factor corrected by 50%

The same scenario as in Figure 59 is presented with one modification in Figure 60 and Figure 61. Electricity to CO_2 conversion factor as well as district heating to CO_2 conversion factor were assumed to be 50% lower in the year 2050 than they were in the year 2011 in Figure 60. Based on the scenario presented in Figure 60, CO_2 emissions could be lower 66% in the year 2050 if compared to the year 2011. Lowering the CO_2 conversion factor is in line with the constant EU efforts in decarbonising the energy supply (electricity). Some countries are even now talking about 100% renewable energy supply (electricity) until 2050 [167].

Finally, if we presume that the electricity and district heating sectors would be fully decarbonised in the year 2050 CO_2 emission could be 90% lower in 2050, if compared to 2011.

Based on these results, the following conclusion could be drawn; ambitious EU goals regarding CO_2 emission reduction for 2050 cannot be achieved purely on the demand side, but require a heavy uptake of renewable energy sources in both electricity and heat sector till 2050.

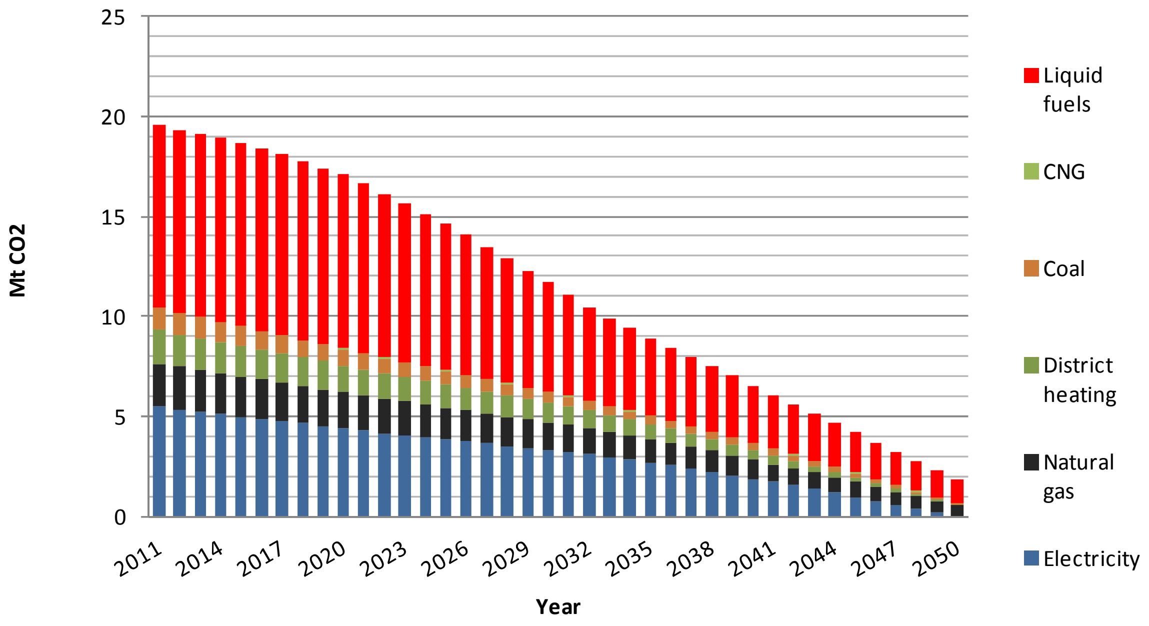


Figure 61 CO_2 emissions of the energy efficiency scenario calculated with the NeD model with 100% renewable electricity generation and district heating sector

3.2 LEAP model: Croatia

As a final task in the model development and testing is the comparison of the NeD methodology and results calculated with the NeD model and the LEAP model. This testing and comparison is possible only within the limitations of the LEAP model. There are two main intentions within the NeD methodology implementation in LEAP. The first one is to compare results and calibrate some mean variables because the LEAP model does not have the ability to perform very deep analyses, in comparison to the NeD model.

The second reason for the NeD methodology implementation in LEAP is to create a user friendly tool that might help policymakers in the future. Due to big complexity, input data wise, the NeD model is not suited for non expert users and cannot serve policy makers in formulating long term energy demand forecast and strategy.

In Figure 62 all five scenarios of the Croatian transport sector are shown, as calculated in Chapter 3.1.2., while in Figure 63 fuel mix of the EE3 scenario is shown. The difference here is the simplified model applied in LEAP. In this case stock turnover method in LEAP was not chosen due to questionable results and problems verifying them. Because of that classic method (energy intensity method) was used. Unfortunately, it was impossible to model vehicle population dynamics in LEAP, so for the purposes of this research already modelled curves from the NeD model were implemented in the LEAP model. Because of this, it was impossible to create detailed energy efficiency improvements like in the NeD model. In the case of NeD model every vehicle entering the system has specific energy intensity depending on the year it enters the system. In the simplified LEAP model energy intensity for every type of vehicle is modelled as average with constant energy efficiency improvements.

Finally, the last problematic issue with the implementation of the NeD methodology into the LEAP model is the question of modal split. LEAP is very hierarchy oriented model. If applying modelling approach oriented to vehicle population, it is impossible to model the intermodal switch. For the purposes of this research the author has modelled usage (kilometres driven or flown) in order to create the same effect as in the NeD model.

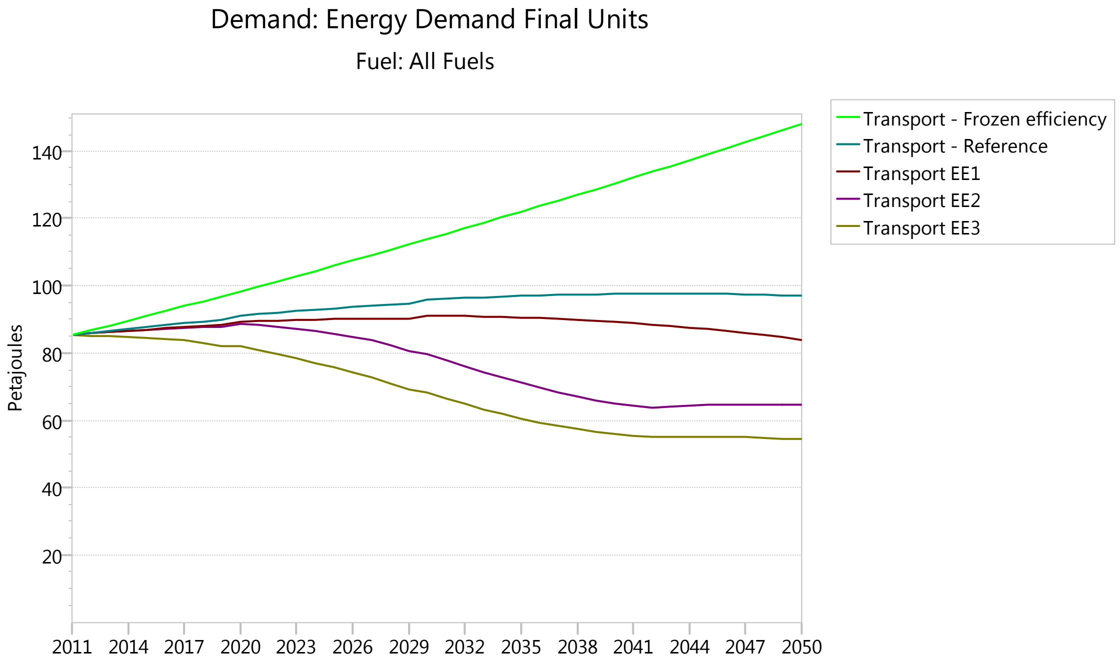


Figure 62 Long term energy demand scenarios of Croatian transport sector – LEAP model

The differences between five modelled scenarios in the NeD model and the LEAP model are shown in Table 17.

Table 17 Comparison of the NeD model and LEAP model results for Croatian transport sector in the year 2050

Scenario	Frozen efficiency	Reference	EE1	EE2	EE3
NeD model (PJ)	148.2	96.7	84.6	64.9	56
LEAP model (PJ)	148.1	96.9	83.9	64.6	54.4

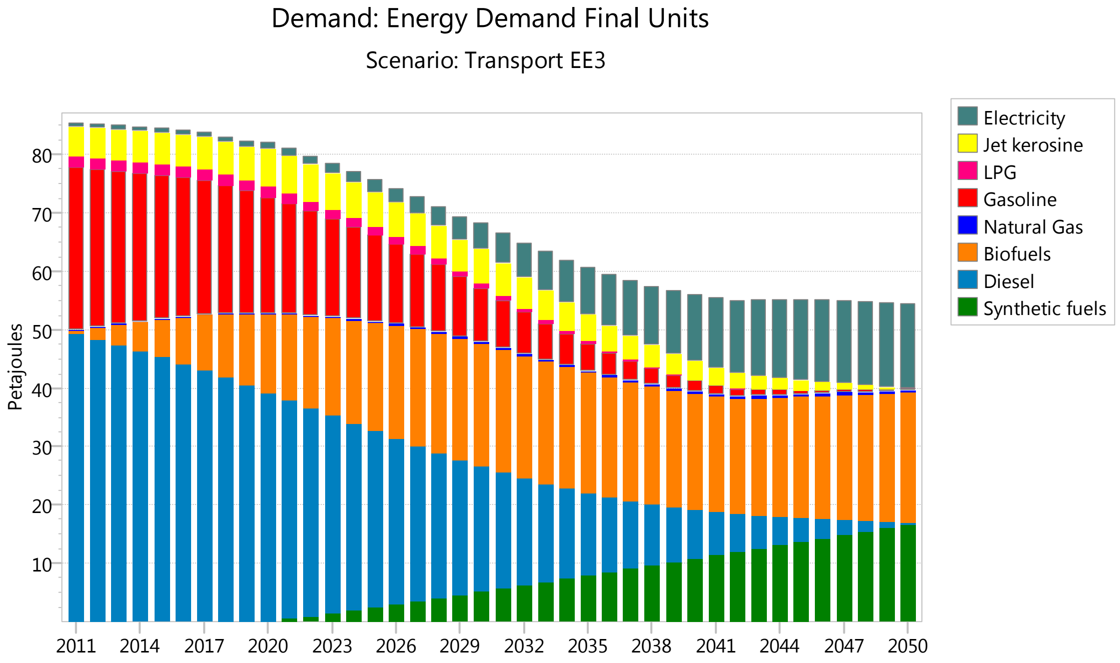


Figure 63 Long term energy demand fuel mix of Croatian transport sector – EE3 scenario in the LEAP model

The same approach was applied to the households sector. In this case it was impossible to do the modelling on the NUTS 3 level in LEAP. Also the NeD methodology was impossible to implement, primarily its thermodynamic approach of calculating useful heat demand. As an alternative, the Croatian household sector in LEAP was modelled on the NUTS 2 level with an average useful energy demand (in kWh/m^2). The scenario results and fuel mix for the EE3 scenario are presented in Figure 64 and Figure 65. The differences between five modelled scenarios in the NeD model and the LEAP model are shown in Table 18.

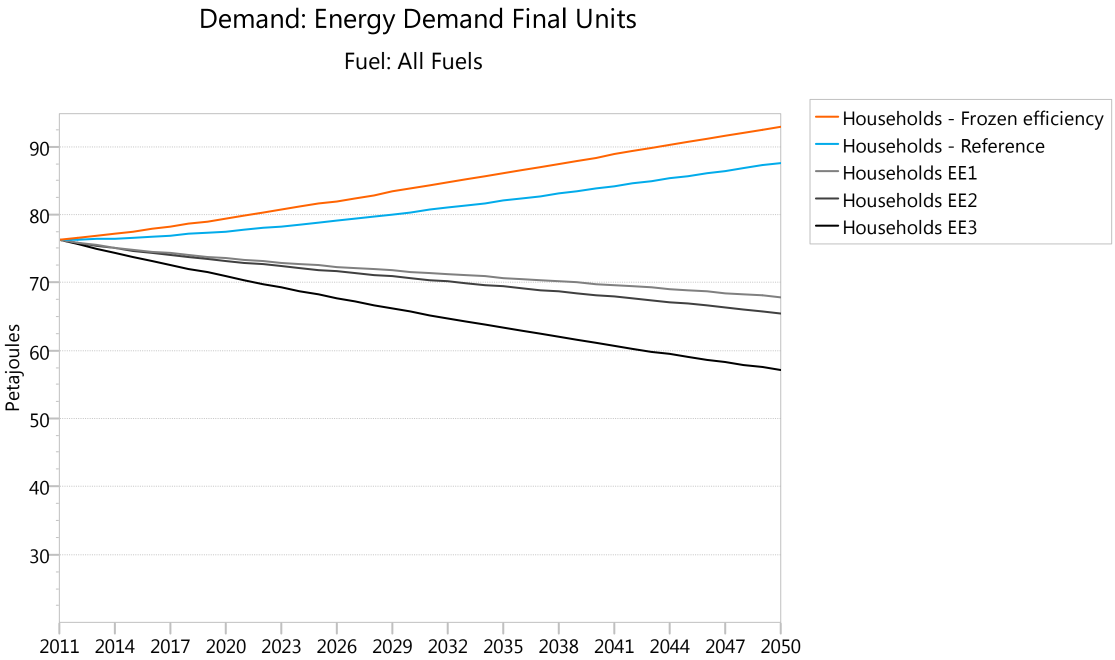


Figure 64 Long term energy demand scenarios of Croatian households sector – LEAP model

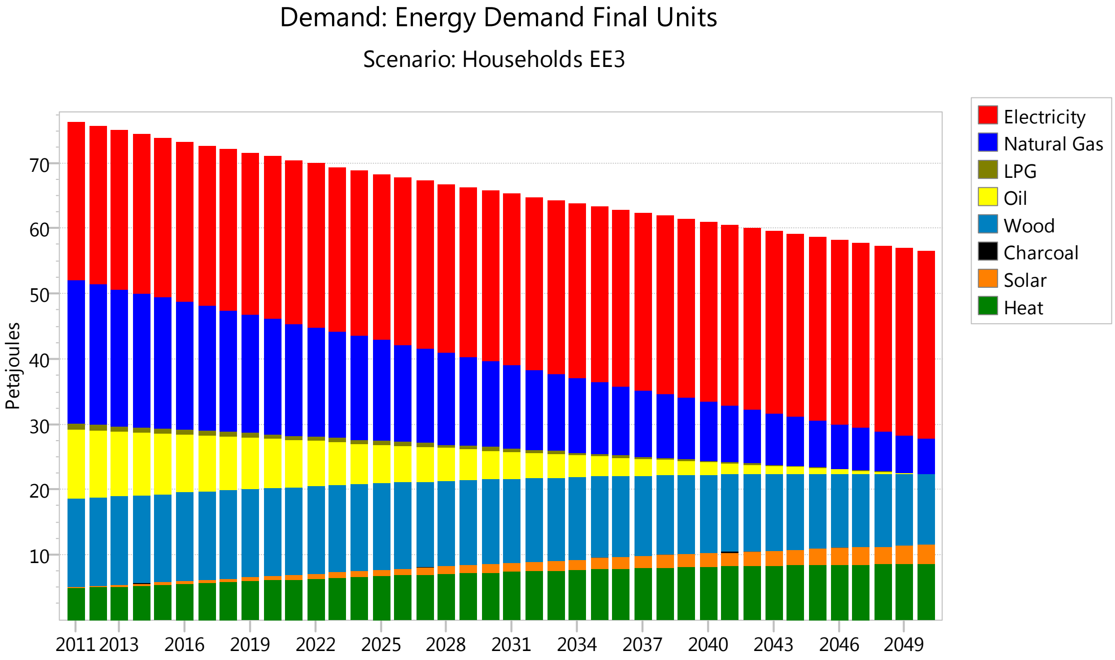


Figure 65 Long term energy demand fuel mix of Croatian households sector – EE3 scenario in the LEAP model

Table 18 Comparison of the NeD model and LEAP model results for Croatian households sector in the year 2050

Scenario	Frozen efficiency	Reference	EE1	EE2	EE3
NeD model (PJ)	93.9	86.1	68.7	65.9	55.2
LEAP model (PJ)	93	87.6	64.9	65.5	56.4

In the case of the industry sector, implementing the NeD methodology into LEAP was difficult due to the high level of details that the NeD model uses. For instance, in the NeD model energy demand of a certain industry subsector is modelled based on all industry products of that sub sector. In Table 19 one typical data input sheet from the NeD model is presented (for Iron and Steel industry). This would be impossible to implement into the LEAP model. As an alternative, the LEAP model calculates the energy demand with one product for each industry subsector (its mean value). The scenario results and fuel mix for the S1 scenario are presented in Figure 66 and Figure 67.

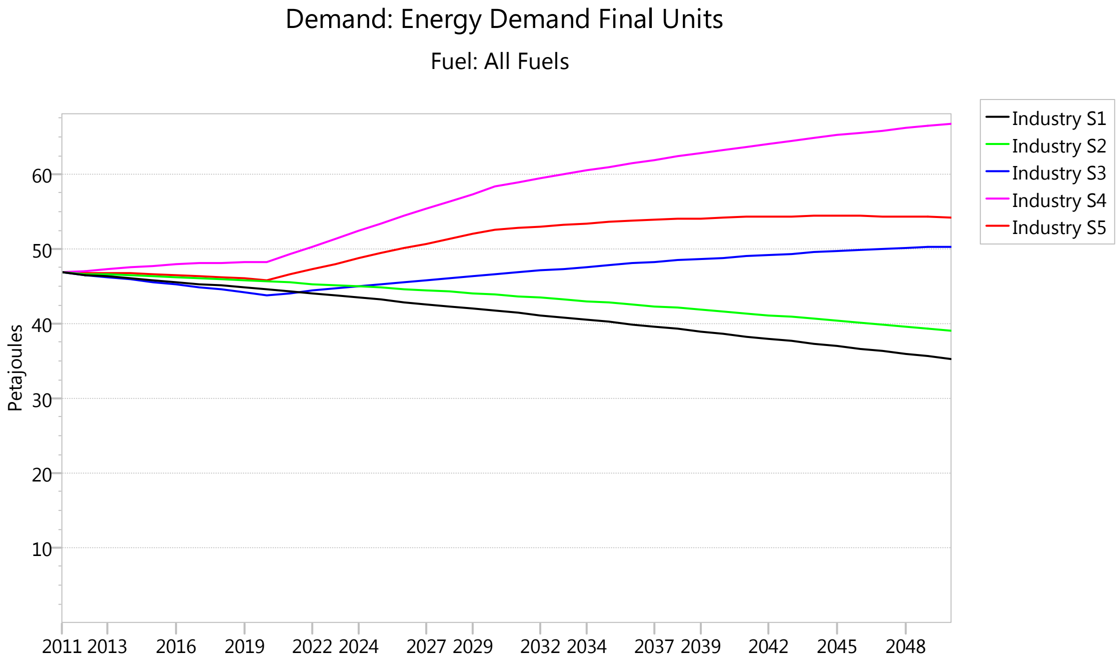


Figure 66 Long term energy demand scenarios of Croatian industry sector – LEAP model

Table 19 An example of typical input data sheet for reference year (NeD model – Industry sector, Iron and Steel subsector)

			TOTAL PROD	TOTAL EXP	TOTAL DOM	IMPORT	DOM %	EXP %
24.10	*Manufacture of basic iron and steel and of ferro-alloys*							
24.10.21.21	***Ingots, other primary forms and long semi-finished products for seamless tubes (of non-alloy steel)***	**t**	**32 648**	**0**	**32 648**	**3627.56**	**100.00%**	**0.00%**
24.10.21.22	***Other ingots. primary forms and long semi-finished products including blanks (of non-alloy steel)***	**t**	**89 111**	**47**	**89 064**	**9896**	**99.95%**	**0.05%**
24.10.23.21	***Ingots. other primary forms and long semi-finished products for seamless tubes (of alloy steel other than of stainless steel)***	**t**	**17 106**	**0**	**17 106**	**1900.67**	**100.00%**	**0.00%**
24.10.61.10	***Ribbed or other deformed wire rod (of non-alloy steel)***	**t**	**88 971**	**6 826**	**82 145**	**9127.22**	**92.33%**	**7.67%**
24.10.61.30	***Wire rod used for concrete reinforcing***	**t**	**0**	**0**	**0**	**0**	**0**	**0**
24.10.74.20	***Welded and cold formed sections (of steel)***	**t**	**243**	**0**	**243**	**27**	**100.00%**	**0.00%**
24.10.75.00	***Railway material (of steel)***	**t**	**23**	**0**	**23**	**2.55**	**100.00%**	**0.00%**
24.20	*Manufacture of tubes, pipes, hollow profiles and related fittings, of steel*					**0**		
24.20.13.30	***Precision tubes and pipes, of circular cross-section, cold-drawn or cold-rolled, seamless, of steel other than stainless steel***	**t**	**36 130**	**27 330**	**8 800**	**977.77**	**24.36%**	**75.64%**
24.20.14.00	***Tubes and pipes, of non circular cross-section, seamless, and hollow profiles, seamless, of steel***	**t**	**900**	**181**	**719**	**79.88**	**79.89%**	**20.11%**
24.20.31.10	***Line pipe, of a kind used for oil or gas pipelines, longitudinally or spirally welded, of an external diameter <= 406.4 mm, of stainless steel***	**t**	**110**	**0**	**110**	**12.22**	**100.00%**	**0.00%**
24.20.33.10	***Tubes and pipes, of circular cross-section, welded, of an external diameter <= 406.4 mm, of stainless steel (excluding line pipe of a kind used for oil or gas pipelines, and casing and tubing used for oil or gas drilling)***	**t**	**941**	**49**	**892**	**99.11**	**94.79%**	**5.21%**
24.20.33.40	***Precision tubes and pipes, of circular cross-section, welded, of an external diameter <= 406,4 mm, of steel other than stainless steel***	**t**	**16 292**	**4 356**	**11 936**	**1326.22**	**73.26%**	**26.74%**
24.20.33.70	***Tubes and pipes, of circular cross-section, hot or cold formed and welded, of an external diameter <= 406.4 mm, of steel other than stainless steel***	**t**	**29 974**	**17 782**	**12 192**	**1354.67**	**40.68%**	**59.32%**
24.20.34.10	***Tubes and pipes, of non-circular cross-section, hot or cold formed and welded, of stainless steel***	**t**	**1 007**	**81**	**926**	**102.89**	**91.96%**	**8.04%**
24.20.34.30	***Tubes and pipes, of square or rectangular cross-section, of a wall thickness <= 2 mm, hot or cold formed and welded, of steel other than stainless steel***	**t**	**4 785**	**180**	**4 605**	**511.6667**	**96.24%**	**3.76%**
24.20.34.50	***Tubes and pipes, of square or rectangular cross-section, of a wall thickness > 2 mm, hot or cold formed and welded, of steel other than stainless steel***	**t**	**5 297**	**160**	**5 137**	**570.77**	**96.98%**	**3.02%**
24.20.34.70	***ubes and pipes, of other cross-section than square or rectangular, hot or cold formed and welded, of steel other than stainless steel***	**t**	**3 634**	**0**	**3 634**	**403.77**	**100.00%**	**0.00%**

24.20.40.10	Flanges, of steel (excluding cast fittings)	t	2 122	0	2 122	235.78	100.00%	0.00%
24.20.40.30	Elbows, bends, couplings, sleeves and other threaded tube or pipe fittings, of steel (excluding cast fittings)	t	815	738	77	8.56	9.45%	90.55%
24.20.40.50	Elbows, bends, couplings and sleeves and other socket welding tube or pipe fittings, of steel (excluding cast fittings)	t	121	0	121	13.44	100.00%	0.00%
24.20.40.73	Butt welding elbows and bends, for tubes or pipes, of steel (excluding cast fittings)	t	654	143	511	56.78	78.13%	21.87%
24.31	Cold forming of pipes							
24.31.10.10	Bars and rods, of non-alloy free-cutting steel, not further worked than cold-formed or cold-finished (e.g. by cold-drawing)	t	120	0	120	13.33	100.00%	0.00%
24.33	Cold forming or folding							
24.33.11.10	Cold formed sections, obtained from flat products, of non alloy steel, not coated	t	8 406	129	8 277	919.6667	98.47%	1.53%
24.33.11.30	Cold formed sections. obtained from flat products, of non alloy steel, coated with zinc	t	11 675	7 552	4 123	458,1111	35.31%	64.69%
24.33.11.50	Angles,shapes and sections, of iron or non-alloy steel, cold-formed or cold-finished and further worked, or not further worked than forget, or forget,or hot-formed by other means and further worked, n.e.s (excluding from flat-rolled products) cold-formed	t	4		4	0.444444	100.00%	0.00%
24.33.12.00	Cold formed sections, obtained from flat products, of stainless steel	t	1 057	0	1 057	117.44	100.00%	0.00%
24.33.20.00	Cold profiled (ribbed) sheets, of non alloy steel	t	1 500	0	1 500	166,67	100.00%	0.00%
24.33.30.00	Structures, solely or principally of iron or steel sheet comprising two walls of profiled (ribbed) sheet with an insulating core (excluding prefabricated buildings)	t	13 083	4 502	8 581	953.44	65.59%	34.41%
24.34	Cold forming of wire							
24.34.11.30	Iron or non-alloy steel wire containing <0.25% of carbon including crimping wire excluding stranded wire, barbed wire used for fencing - duplex wire - saw-tooth wire, insulated electric wire	t	43 245	9	43 236	4804	99.98%	0.02%
24.51	Casting of iron							
24.51.11.10	Malleable iron castings for land vehicles, piston engines and other machinery and mechanical appliances	t	0	0	0	0	0	0
24.51.12.20	Ductile iron castings for transmission shafts, crankshafts, camshafts, cranks, bearing housings and plain shaft bearings (excluding for bearing housings incorporating ball or roller bearings)	t	370	137	233	25.89	62.97%	37.03%
24.51.12.40	Other parts of piston engines and mechanical engineering (nodular iron castings)	t	476	0	476	52.89	100.00%	0.00%
24.51.12.50	Ductile iron castings for machinery and mechanical appliances excluding for piston engines	t	12 068	7 217	4 851	539	40.20%	59.80%
24.51.13.10	Grey iron castings for land vehicles (excluding for locomotives or rolling stock, construction industry vehicles)	t	3 024	2 100	924	102.67	30.56%	69.44%
24.51.13.20	Grey iron castings for transmission shafts, crankshafts, camshafts, cranks, bearing housings and plain shaft bearings (excluding bearing housings incorporating ball or roller bearings)	t	0	0	0	0	0	0
24.51.13.40	Other parts of piston engines and	t	2 298	562	1 736	192.89	75.54%	24.46%

	mechanical engineering (cast iron: not ductile)							
24.51.13.50	***Grey iron castings for machinery and mechanical appliances excluding for piston engines***	**t**	**18 561**	**7 118**	**11 443**	**1271.44**	**61.65%**	**38.35%**
24.51.13.90	***Grey iron castings for locomotives/rolling stock/parts, use other than in land vehicles, bearing housings, plain shaft bearings, piston engines, gearing, pulleys, clutches, machinery***	**t**	**2 199**	**0**	**2 199**	**244.33**	**100.00%**	**0.00%**
24.51.20.00	***Tubes, pipes and hollow profiles of cast iron excluding tubes, pipes, hollow profiles made into identifiable parts of articles, such as sections of central heating radiators and machinery parts***	**t**	**0**	**0**	**0**	**0**	**0**	**0**
24.52	*Casting of steel*							
24.52.10.50	***Steel castings for machinery and mechanical appliances excluding piston engines, turbojets, turboprops, other gas turbines, lifting or handling equipment, construction industry machinery/vehicles***	**t**	**2 311**	**0**	**2 311**	**256.78**	**100.00%**	**0.00%**
24.52.10.90	***Steel castings for locomotives/rolling stock/parts, use other than in land vehicles, bearing housings, plain shaft bearings, piston engines, gearing, pulleys, clutches, machinery***	**t**	**133**	**0**	**133**	**14.78**	**100.00%**	**0.00%**
	TOTAL		451 544	87 202	364 342	40 482	80.69%	19.31%

The differences between five modelled scenarios in the NeD model and the LEAP model are shown in Table 20.

Table 20 Comparison of the NeD model and LEAP model results for Croatian industry sector in the year 2050

Scenario	S1	S2	S3	S4	S5
NeD model (PJ)	36.1	39.6	52.1	71.8	56.8
LEAP model (PJ)	35.3	39	50.3	66.7	54.2

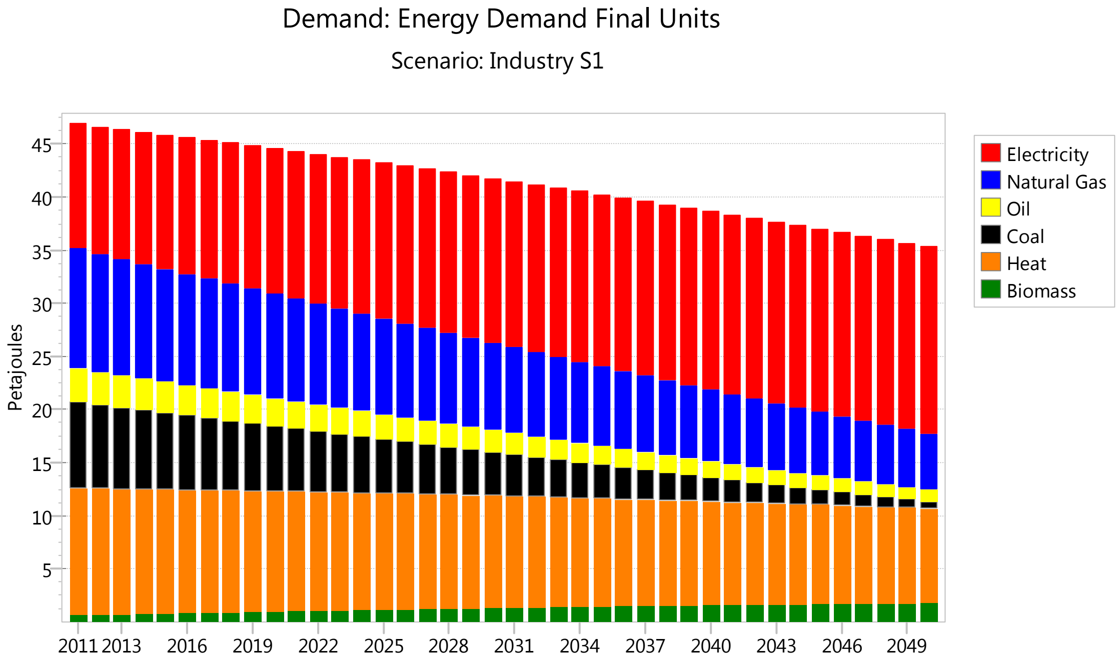


Figure 67 Long term energy demand fuel mix of Croatian industry sector – S1 scenario in the LEAP model

In Figure 68 and Figure 69 the LEAP results for the Croatian services sector are presented. Previously mentioned constraints used in the households sector are applied here as well.

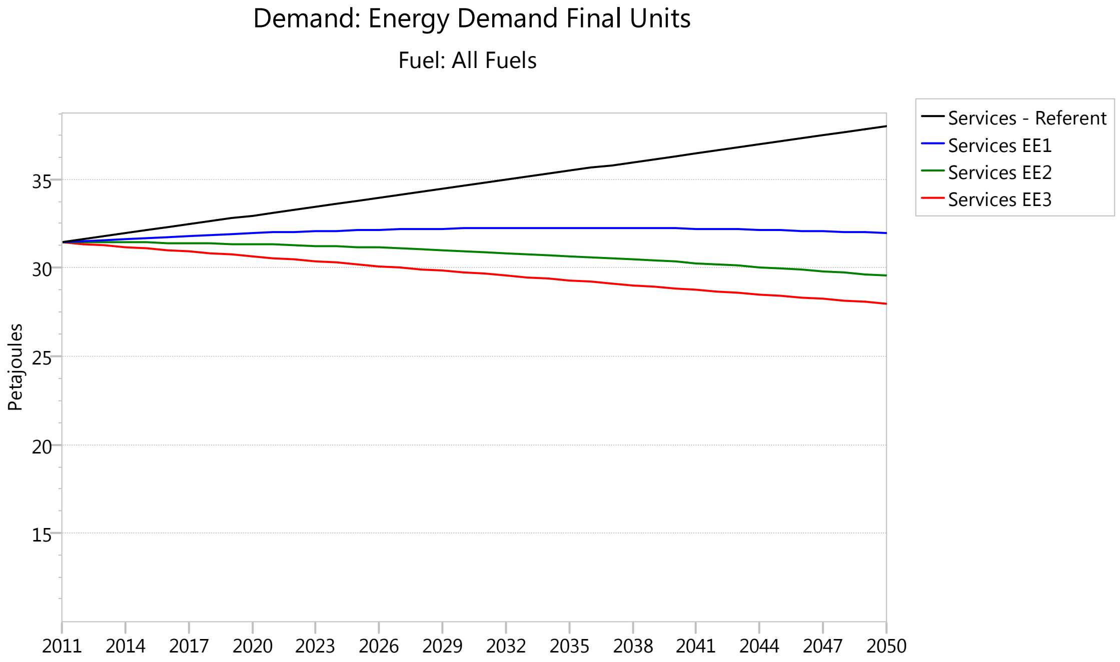


Figure 68 Long term energy demand scenarios of Croatian services sector – LEAP model

The differences between modelled scenarios in the NeD model and the LEAP model are shown in Table 21.

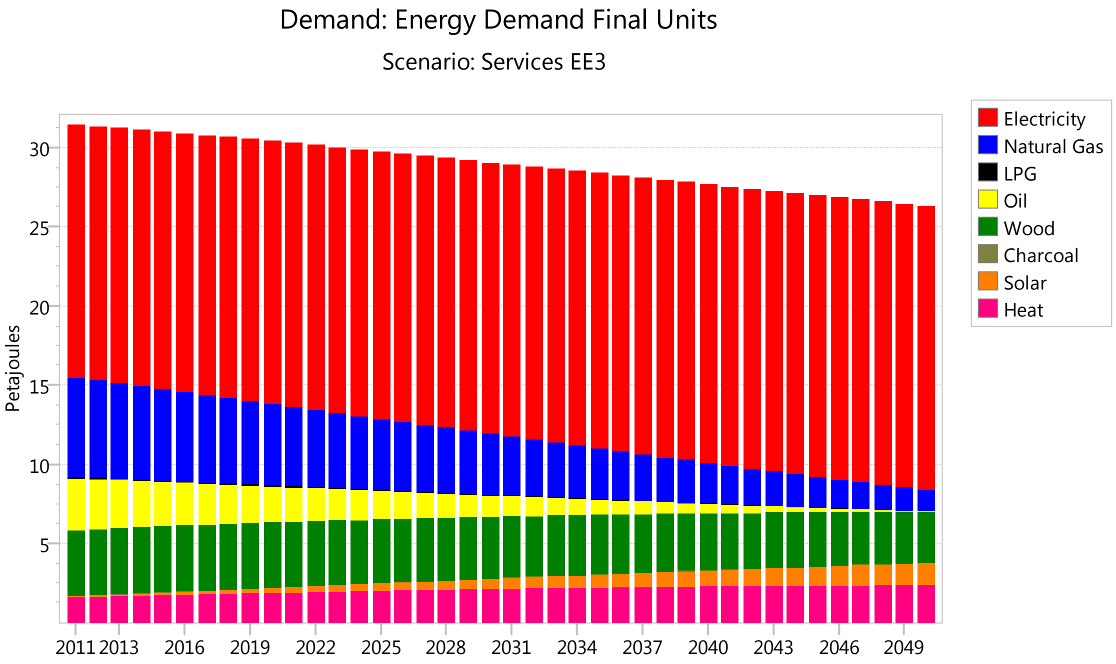


Figure 69 Long term energy demand fuel mix of Croatian services sector – EE3 scenario in the LEAP model

Table 21 Comparison of the NeD model and LEAP model results for Croatian services sector in the year 2050

Scenario	Reference	EE1	EE2	EE3
NeD model (PJ)	37	31.8	29	27.4
LEAP model (PJ)	37.9	31.9	29.5	27.1

3.3 Comparison of three selected models and results

Through this research a comparison between the official Croatian National Energy Strategy demand projections and the results of the NeD model will be given. Another model that will be compared with the NeD model and its results is Primes EU28, which recently included Croatia in its latest version. First, a comparison for four main economic sectors will be given (households, transport, industry and services) and finally a national comparison will be shown, together with all energy wedges presented in Figure 56. The Croatian National Energy Strategy gives energy demand forecast only till 2020, with a look of 2030. Because of that, in all the following figures, national strategy results will be given just for these two years. Primes EU28 gives energy demand projections till 2050 but with very limited methodology behind them.

3.3.1 Households sector results

Comparing national energy demand projections with the households NeD model results leads to significant differences, as can be seen in Figure 70.

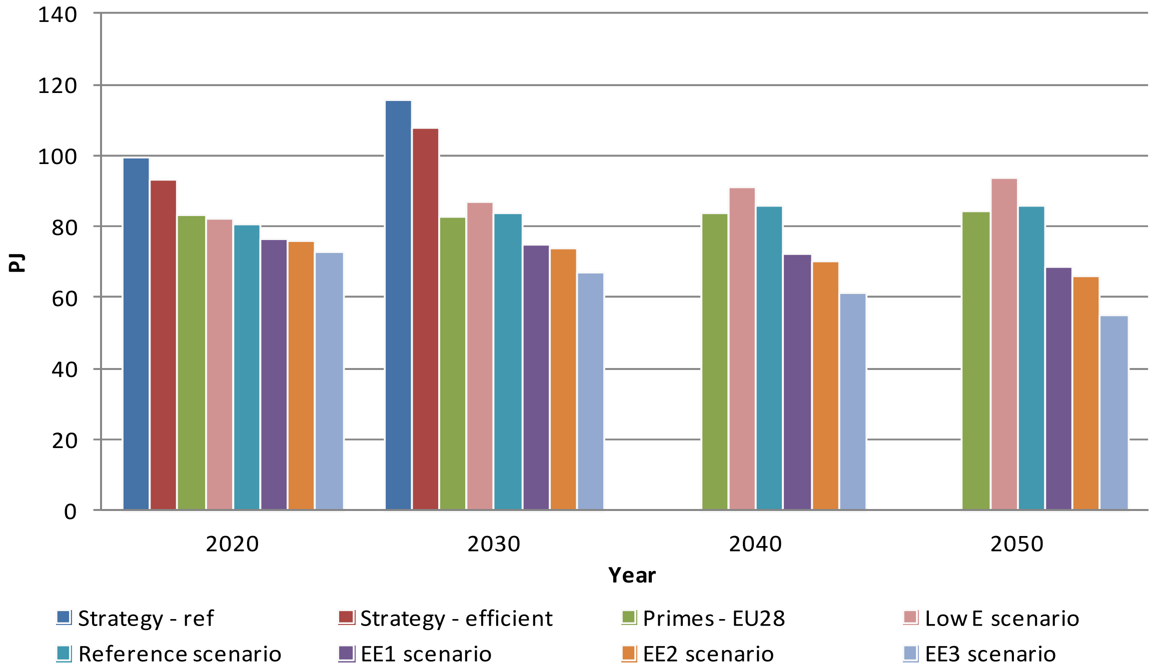


Figure 70 Final energy demand projections of Croatian households sector

The most challenging scenario (EE3) is 26.8% lower than the national strategy reference scenario (Strategy – ref) and 21.7% lower than the national strategy efficient scenario (Strategy – efficient) in 2020. In 2030 this difference is 42% for the first case and 37.8% for the second case. As seen in Figure 70, Primes EU28 results are very similar to the NeD reference scenario in 2020, 2030, 2040 and 2050.

This leads to a conclusion that Primes EU28 uses quite conservative approach towards energy policy measures in the future period. In all the years the difference between Primes EU28 and the NeD reference scenario is less than 2.5 PJ. The added value of the NeD model is its capability to identify energy policy measures beyond the reference scenario of Primes EU28 results. In 2050 these possible measures could come up to 29.3 PJ, if comparing Primes EU28 and the EE3 scenario. One of the possible reasons for this difference could lie in the methodology's approach. The NeD model, based on its bottom up end use methodology, could give a more detailed image of all the trends that would be important for future energy demand.

3.3.2 Transport sector results

The same statement on overestimated figures of the National Energy Strategy could be applied here as well (Figure 71).

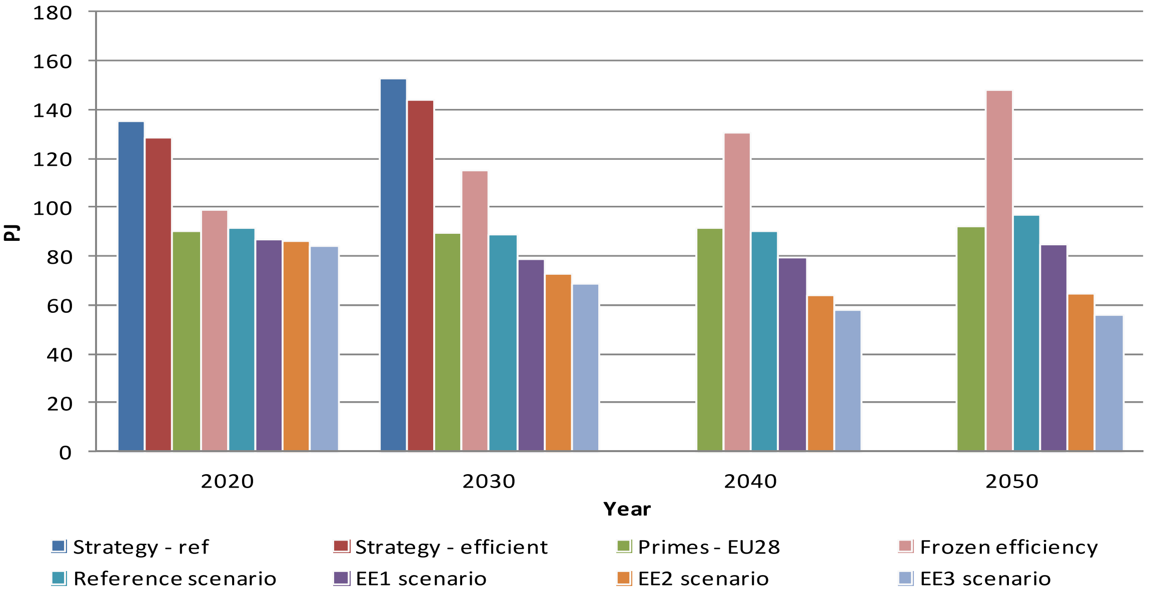


Figure 71 Final energy demand projections of Croatian transport sector

If a comparison of the two extreme scenarios is made, Strategy - ref and the NeD EE3 scenario, possible energy savings in 2020 could be 37.5%, while in 2030 they could increase to 55%.

As well in this case, the difference between Primes EU28 and the NeD reference scenario is quite small. In all the years this difference is less than 4 PJ. In 2050 possible energy policy measures could come up to 36.5 PJ, if comparing Primes EU28 and the EE3 scenario.

It can be concluded that different energy policies, technology improvements as well as other incentives, will lead to a lower national final energy demand. This is a win-win situation for the country because it allows for the further development of new technologies, new investment cycles, an increase in employment and, at the same time, it suggests lower dependence on fossil fuel imports.

3.3.3 Industry sector results

As it can be seen in Figure 72 the difference between the NeD S1 scenario and the Strategy – ref in 2020 is 41 PJ. If we take into consideration that the whole industry sector consumed 46.96 PJ in the reference year (2011) this presents a big discrepancy. This difference grows to 62 PJ in the year 2030. It is clearly visible that the Croatian Energy Strategy must be taken with a certain reserve considering all the possible parameters that might influence future energy demand. This uncertainty simply proves that the energy strategy must take into consideration all influential factors in the industry as well as the comprehensive analysis of the energy data sector by sector. Of course, market disturbances such as the economic crisis cannot be predicted in an accurate fashion, but such occurrences must be taken into account.

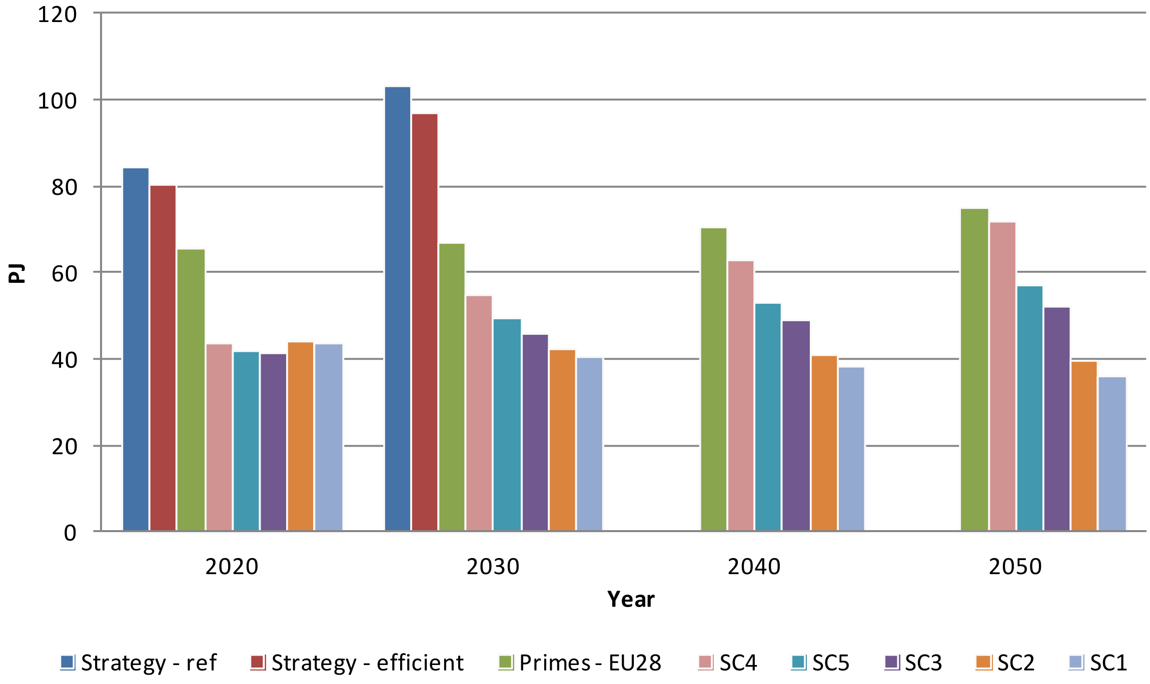


Figure 72 Final energy demand projections of Croatian industry sector

3.3.4 Services sector results

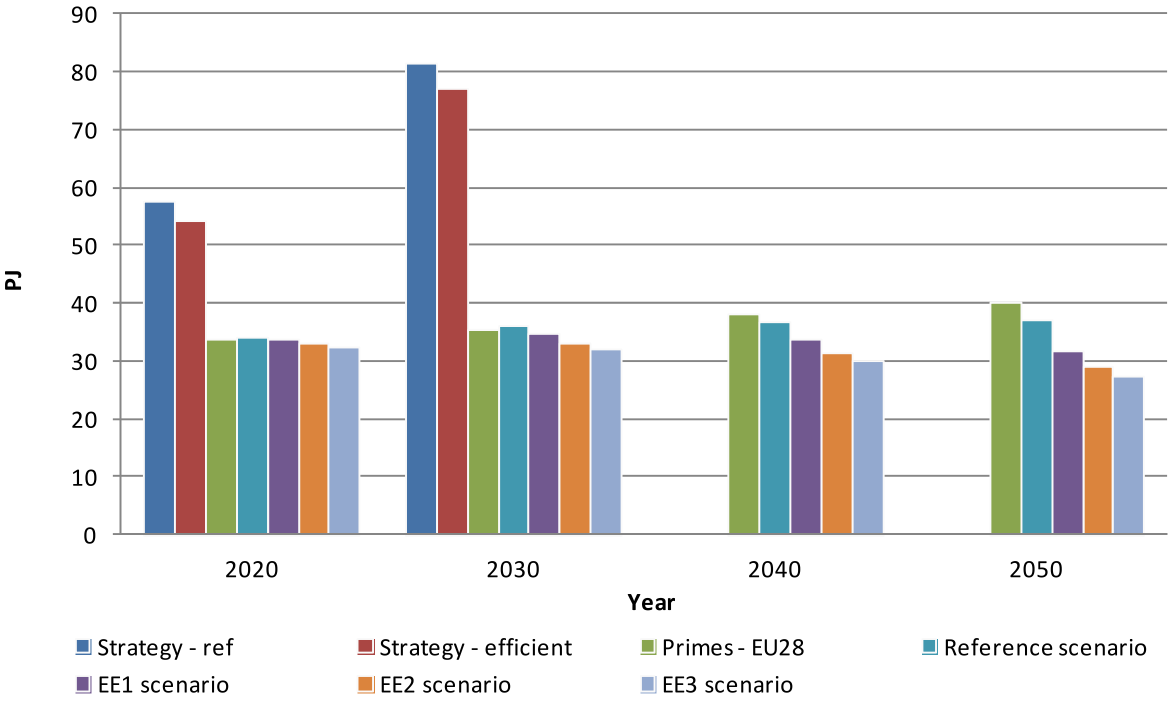


Figure 73 Final energy demand projections of Croatian services sector

Similar conclusions and comments could be drawn for the services sector as well as the previous ones, especially the households sector. In Figure 73 significant discrepancies between the Croatian Energy Strategy and the NeD results can be seen. In 2030, the Croatian energy strategy predicts 155% higher energy demand than calculated through the EE3 scenario of the NeD model.

As well in this case the difference between Primes EU28 and the NeD reference model is quite small. In all the years this difference is less than 3.5 PJ. In 2050 possible energy policy measures could come up to 12.8 PJ, if comparing Primes EU28 and the EE3 scenario.

3.3.5 National results comparison

Finally, after all sectoral energy wedges have been implemented, the comparison of three selected models and results on a national level is shown in Figure 74. The difference between Strategy – ref and the NeD reference scenario in 2020 is 136 PJ while this difference in the year 2030 rises to 217.8 PJ. This difference is bigger than the whole Croatian energy demand in 2050, calculated with the NeD model, with the implementation of energy policy.

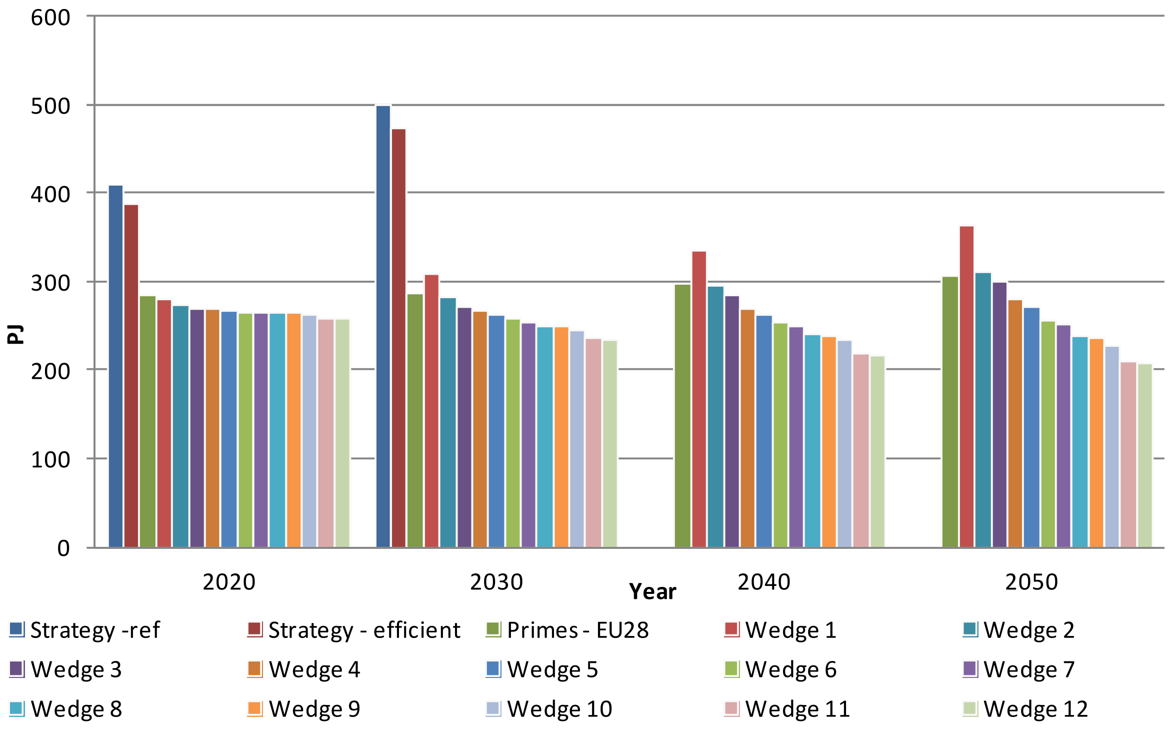


Figure 74 Croatian final energy demand projections

Differences and similarities between Primes EU28 and the NeD reference scenario have already been explained and quantified in previous paragraphs. On a national level the differences are 4% in 2020, 1.5% in 2030, 0.7% in 2040 and 1.8% in 2050.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Decarbonisation of Croatian final energy demand

The NeD model presents a unified energy model that can be used for the analysis of a whole country's final energy demand. Its methodology is applicable to any other country under the condition that all local specifics would be described and quantified through the model. In the case of Croatia, the results calculated by the NeD model have shown significant energy demand reduction potentials as well as GHG emission potentials in the forthcoming long term period. The transport sector, as well as buildings, presented the biggest potential in energy demand management, which was fairly expected. If analysing the energy efficiency scenario calculated with the NeD model, after all the suggested energy efficiency wedges were implemented, energy demand in the year 2050 could be almost 24% lower, if compared to the year 2011.

4.1.1 Possible pathways

Croatian households sector presents a big opportunity for energy savings and penetration of renewable energy sources in the future. One of the key elements is enforcing current building codes and directives for all the buildings that are being built or renovated. Strict application of these codes and directives would lead to significant energy savings. The useful heat demand difference in the year 2050 between 1% refurbishment rate and 3% refurbishment rate for the whole buildings stock is almost 12%. One of the key elements regarding energy consumption in the households sector would be introducing new regulations that would require new and refurbished buildings to produce their energy locally, or to be nearly zero energy buildings. The results of the extreme, 3% yearly refurbishment rate, scenario show that at least 41% of useful heat demand should be satisfied locally and from renewable energy sources in the year 2050. For this to be applicable, changes regarding nearly zero energy buildings, both new and refurbished ones, need to be done in the mid 2020s. For Croatian households sector, turning heavily to biomass, heat pumps and district heating seems the most logical choice for the future, with heat pumps being the most favourable because of their positive impact on lowering final energy demand. From the energy efficiency perspective, there are two main tasks in achieving lower final energy demand. The first one is lowering actual needs, with the implementation of different legal mechanisms, while the other one is the technology impact. This means satisfying all of the needs with the most efficient technology and fuel type.

Modelling the future energy demand of the transport sector can be very challenging and complex. The NeD model helps us analyse different legal or financial mechanisms that are directly related to future energy demand. To date, the model has been proven to be a reliable tool for the basic assessment of the future energy demand of the transport sector. Its methodology can be applied to other energy systems and transport sectors, considering the specific factors and boundary conditions, such as modal structure or bunker fuel exclusion. The results show that electric vehicles will play a key role in future transport systems, allowing for significant savings in final energy demand. This means more vehicles and kilometres driven with lower final energy demand.

The NeD model tries to incorporate all relevant factors that directly influence energy consumption, in the industry sector, although energy demand modelling of the industry sector was proven to be a challenging task. One of the main challenges is because of the large number of influential factors as well as constantly changing market conditions. The energy consumption in Croatian industry has significantly fallen due to the economic crisis. The NeD model was developed to assess the future possible outcomes related to the energy demand of Croatian industry and to prepare the final energy demand projections for future work on modelling the overall energy situation in Croatia. It was tested on the reference year (2011) and used to predict future production capacities for the domestic market and export, as well as import. The model is highly flexible, i.e. the input values can be changed to extreme values which results in completely different outcomes. Even though the Croatian industry is currently in a downfall the future increases in production will cause a significant increase in final energy consumption. This increase can be mitigated through implementation of energy efficiency measures and renewable energy sources. Energy efficiency measures have the highest influence on the final energy consumption in the industry since the best way to save energy is not to use it. Five scenarios were developed for assessing the final energy demand projections based on different input parameters. The results have shown that Scenarios 1 and 2 have the lowest final energy demand in 2050, which is caused by an increase in import, decrease in domestic production, implementation of energy efficiency measures and renewable energy sources. Scenario 3 resulted in a higher final energy consumption, which is caused by higher production capacities for the domestic market and export while at the same time reducing the import quantities. In Scenarios 4 and 5 the growth or energy consumption is caused by a sharp increase in export capacities and increase in consumption on the domestic market. The development of the future situation in the industry is uncertain and depends on many factors and is subject to both technical and economic influences, domestic and foreign. Despite that, industry should be carefully observed and suitable support mechanisms should be implemented in order to support future development.

4.1.2 A view towards the year 2050

The EU's commitment in achieving a reduction of emissions by 80% to 95% by 2050 compared to 1990, as agreed by the European heads of state and government, will require enhanced efforts from member states. Based on the results of this research, in Croatian case, energy demand measures will not be enough to reach these ambitious goals. In 2050, with electricity and district heating system unchanged, demand side measures could reduce CO_2 emissions by 41% if comparing them to the reference year.

Clearly, in order to achieve these goals decarbonisation of the electricity generation sector, together with the district heating sector, is necessary. Maximum GHG emission savings calculated with the NeD model, by applying 50% increase of renewable sources in the electricity and district heating sectors, were 66% in the year 2050 if compared to the reference year. This more or less means that in order to achieve EU 2050 objectives, Croatia will have to start thinking about 100% renewable electricity and district heating systems, as a long term objective.

4.2 Bottom-up to top-down principles

The comparison between the three models and their results in Chapter 3.3.5 clearly shows that long term energy demand forecasts need to be based on the bottom up approach. Certain integration of top down methodology would be beneficial, especially when modelling energy price influence or rebound effect [163][164] but the top down approach should not be the basis for long term energy demand planning. If energy policy needs to be quantified and described, bottom up methodology, focused on end users, needs to be applied.

One of the conclusions drawn from the presented results is the fact that the Croatian Energy Strategy demand scenarios need to be considered with a certain reserve since bottom up modelling shows room for implementing different mechanisms that ultimately have the consequence of lower final energy demand.

4.3 Energy demand modelling constraints

The main constraint in building quality bottom up models is reliable input data. Bottom up models require lots of various input data, from purely macroeconomic to strictly technical. In previous chapters difficulties of forecasting macroeconomic variables have been explained. Similar is with modelling various learning curves for energy technologies. As an alternative to these constraints, long term energy demand models need to allow various sensitivity analyses in order to examine possible boundary conditions and extreme scenarios.

In the case of Croatia problem of unreliable input data still exist, due to inconsistent energy statistics. The situation has improved in the last five years, but there is still a lot of room for improvement. One of the positive incentives is establishing “the energy department” under the Croatian Bureau of Statistics that would deal with tracking energy consumption and calculating various energy indicators. Another positive impact is the Croatian accession to the EU, which forced the national government to tackle the energy statistic issue. Especially because this issue is crucial in reporting procedures to the Commission regarding national targets on energy savings, RES requirements and GHG emission reduction.

4.4 Recommendations for energy demand models

Integration between demand and supply modelling is crucial in the future. Energy planning should turn towards integral models. It is no longer enough to calculate future energy demand, but it is important to know its distribution throughout the years. This is the only way to model various energy systems that would integrate a big amount of renewable energy sources. In this situation the most interesting research on the demand side would be the influence and the possibilities of flexible energy demand [165] [166].

5 LITERATURE

1. Marko Sencar, Viljem Pozeb, Tina Krope, Development of EU (European Union) energy market agenda and security of supply, Energy, Volume 77, 1 December 2014, Pages 117-124
2. Lidia Hrnčević, Igor Dekanić, Daria Karasalihović Sedlar, Analiza sigurnosti opskrbe prirodnim plinom u Republici Hrvatskoj, Energija, Volume 57, No. 6, 2008.
3. Gonzalo Escribano Francés, José María Marín-Quemada, Enrique San Martín González, RES and risk: Renewable energy's contribution to energy security. A portfolio-based approach, Renewable and Sustainable Energy Reviews, Volume 26, October 2013, Pages 549-559
4. Croatian historical energy balances, Energy Institute Hrvoje Požar, www.eihp.hr [accessed 02.05.2013]
5. Sujeetha Selvakkumaran, Bundit Limmeechokchai, Low carbon society scenario analysis of transport sector of an emerging economy—The AIM/Enduse modelling approach, Energy Policy, Available online 23 October 2014, ISSN 0301-4215, http://dx.doi.org/10.1016/j.enpol.2014.10.005
6. Shuichi Ashina, Junichi Fujino, Toshihiko Masui, Tomoki Ehara, Go Hibino, A roadmap towards a low-carbon society in Japan using backcasting methodology: Feasible pathways for achieving an 80% reduction in CO2 emissions by 2050, Energy Policy, Volume 41, February 2012, Pages 584-598
7. Patrik Söderholm, Roger Hildingsson, Bengt Johansson, Jamil Khan, Fredrik Wilhelmsson, Governing the transition to low-carbon futures: A critical survey of energy scenarios for 2050, Futures, Volume 43, Issue 10, December 2011, Pages 1105-1116
8. Patrik Söderholm, Roger Hildingsson, Bengt Johansson, Jamil Khan, Fredrik Wilhelmsson, Governing the transition to low-carbon futures: A critical survey of energy scenarios for 2050, Futures, Volume 43, Issue 10, December 2011, Pages 1105-1116
9. Filipa Amorim, André Pina, Hana Gerbelová, Patrícia Pereira da Silva, Jorge Vasconcelos, Victor Martins, Electricity decarbonisation pathways for 2050 in Portugal: A TIMES (The Integrated MARKAL-EFOM System) based approach in

closed versus open systems modelling, Energy, Volume 69, 1 May 2014, Pages 104-112

10. Alessandro Chiodi, Maurizio Gargiulo, Fionn Rogan, J.P. Deane, Denis Lavigne, Ullash K. Rout, Brian P. Ó Gallachóir, Modelling the impacts of challenging 2050 European climate mitigation targets on Ireland's energy system, Energy Policy, Volume 53, February 2013, Pages 169-189
11. Roadmap for moving to low-carbon economy in 2050, European Commission [http://ec.europa.eu/clima/policies/roadmap/index_en.htm accessed: 20.11.2014]
12. Ćosić B, Markovska N, Krajačić G, Taseska V, Duić N. Environmental and economic aspects of higher RES penetration into Macedonian power system. Appl. Therm. Engineering 2011, doi: 10.1016/j.applthermaleng.2011.10.042
13. Krajačić G, Duić D, da Graça Carvalho M. How to achieve a 100% RES electricity supply for Portugal?. Appl. Energy 2011;88:508-517
14. Alberg Østergaard P, Vad Mathiesen B, Möller B, Lund H. A renewable energy scenario for Aalborg Municipality based on low-temperature geothermal heat, wind power and biomass. Energy 2010;35:4892-4901
15. Krajačić G, Duić N, Zmijarević Z, Vad Mathiesen B, Anić Vučinić A, da Graca Carvalho M. Planning for a 100% independent energy system based on smart energy storage for integration of renewables and CO2 emissions reduction. Appl Therm. Engineering 2011;31:2073-2083
16. Hong L., Lund H., Mathiesen B. V., Moller B., 2050 pathway to an active renewable energy scenario for Jiangsu province, Energy Policy, Vol. 53, pp 267-278, 2013
17. Yu S., Zhu K., A hybrid procedure for energy demand forecasting in China, Energy, Vol. 37, pp 396-404, 2012
18. Kialashaki A., Reisel J. R., Modeling of the energy demand of the residential sector in the United States using regression models and artificial neural networks, Applied Energy, Vol. 108, pp 271-280, 2013
19. Bhattacharyya S. C., Timilsina G. R., Modelling energy demand of developing countries: Are the specific features adequately captured, Energy Policy, Vol. 38, pp 1979-1990, 2010
20. Dedinec A., Markovska N., Taseska V., Duić N., Kanevce G., Assessment of climate change mitigation potential of the Macedonian transport sector, Energy, Vol. 57, pp 177-187, 2013

21. Ćosić B., Markovska N., Krajačić G., Taseska V., Duić N., Environmental and economic aspects of higher RES penetration into Macedonian power system, Applied Thermal Engineering, Vol. 43, pp 158-162, 2012
22. EUROSTAT, http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/ [accessed 02.05.2013]
23. Iñigo Capellán-Pérez, Margarita Mediavilla, Carlos de Castro, Óscar Carpintero, Luis Javier Miguel, Fossil fuel depletion and socio-economic scenarios: An integrated approach, Energy, Volume 77, 1 December 2014, Pages 641-666
24. The European Strategic Energy Technology Plan (SET-Plan), http://ec.europa.eu/energy/en/topics/technology-and-innovation/strategic-energy-technology-plan [accessed 24.02.2015]
25. Keywan Riahi, Arnauf Grubler, Nebojsa Nakicenovic, Scenarios of long term socio economic and environmental development under climate stabilization, Technological Forecasting & Social Change, Volume 74, 2007, 887-935.
26. Pukšec, Tomislav; Krajačić, Goran; Lulić, Zoran; Vad Mathiesen, Brian; Duić, Neven. Forecasting long-term energy demand of Croatian transport sector. Energy, Volume 57, (2013), Pages 169-176
27. Mei Sun, Xiaofang Wang, Ying Chen, Lixin Tian, Energy resources demand-supply system analysis and empirical research based on non-linear approach, Energy, Volume 36, Issue 9, September 2011, Pages 5460-5465.
28. EU Energy, transport and GHG emissions trends to 2050, European Commission [http://ec.europa.eu/energy/observatory/trends_2030/doc/trends_to_2050_update_2013.pdf accessed: 17.11.2014]
29. Strategija energetskog razvoja Republike Hrvatske [http://narodne-novine.nn.hr/clanci/sluzbeni/2009_10_130_3192.html accessed 20.11.2014]
30. McKinsey&Company, 2007. Reducing US Greenhouse Gas Emissions: How Much at What Cost?
31. McKinsey&Company, 2009. Unlocking Energy Efficiency in the US Economy.
32. Kieran Whyte, Hannah E. Daly, Brian P. Ó Gallachóir, Modelling HGV freight transport energy demand in Ireland and the impacts of the property construction bubble, Energy, Volume 50, 1 February 2013, Pages 245-251.
33. Thoreau Rory Tooke, Michael van der Laan, Nicholas C. Coops, Mapping demand for residential building thermal energy services using airborne LiDAR, Applied Energy, Volume 127, 15 August 2014, Pages 125-134

34. In-Ae Yeo, Seong-Hwan Yoon, Jurng-Jae Yee, Development of an urban energy demand forecasting system to support environmentally friendly urban planning, Applied Energy, Volume 110, October 2013, Pages 304-317
35. T.V. Ramachandra, B.V. Shruthi, Spatial mapping of renewable energy potential, Renewable and Sustainable Energy Reviews, Volume 11, Issue 7, September 2007, Pages 1460-1480
36. Croatian bureau of statistics – Population projections till 2051 [http://www.dzs.hr/Hrv/important/Notices/projekcije_stanovnistva_2004-2051.pdf accessed 25.11.2014]
37. Pukšec, Tomislav; Mathiesen, Brian Vad; Duić, Neven. Potentials for energy savings and long term energy demand of Croatian households sector. // Applied energy. 101 (2013) , SI; 15-25.
38. L. Dusonchet, E. Telaretti, Comparative economic analysis of support policies for solar PV in the most representative EU countries, Renewable and Sustainable Energy Reviews, Volume 42, February 2015, Pages 986-998
39. A Roadmap for moving to a competitive low carbon economy in 2050, European Commission – (COM 2011 (2012))
40. Humberto E. Garcia, Amit Mohanty, Wen-Chiao Lin, Robert S. Cherry, Dynamic analysis of hybrid energy systems under flexible operation and variable renewable generation – Part I: Dynamic performance analysis, Energy, Volume 52, 1 April 2013, Pages 1-16
41. Stefan Weitemeyer, David Kleinhans, Thomas Vogt, Carsten Agert, Integration of Renewable Energy Sources in future power systems: The role of storage, Renewable Energy, Volume 75, March 2015, Pages 14-20
42. Pil Seok Kwon, Poul Østergaard, Assessment and evaluation of flexible demand in a Danish future energy scenario, Applied Energy, Volume 134, 1 December 2014, Pages 309-320
43. Jaume Salom, Anna Joanna Marszal, Joakim Widén, José Candanedo, Karen Byskov Lindberg, Analysis of load match and grid interaction indicators in net zero energy buildings with simulated and monitored data, Applied Energy, Volume 136, 31 December 2014, Pages 119-131
44. Kumudhini Ravindra, Parameshwar P. Iyer, Decentralized demand–supply matching using community microgrids and consumer demand response: A scenario analysis, Energy, Volume 76, 1 November 2014, Pages 32-41

45. Shree Raj Shakya, Ram M. Shrestha, Transport sector electrification in a hydropower resource rich developing country: Energy security, environmental and climate change co-benefits, Energy for Sustainable Development, Volume 15, Issue 2, June 2011, Pages 147-159
46. B. Asare-Bediako, W.L. Kling, P.F. Ribeiro, Future residential load profiles: Scenario-based analysis of high penetration of heavy loads and distributed generation, Energy and Buildings, Volume 75, June 2014, Pages 228-238
47. Ayman Mohamed, Ala Hasan, Kai Sirén, Fulfillment of net-zero energy building (NZEB) with four metrics in a single family house with different heating alternatives, Applied Energy, Volume 114, February 2014, Pages 385-399
48. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings [http://eur-lex.europa.eu/legal-content/EN/ALL/;ELX_SESSIONID=WGyjJqncZQz3zkpkdcGVh7pDqkM7bRQJl0WNp0pFTdsByN67VZy1!-756383375?uri=CELEX:32010L0031 accessed: 17.11.2014.]
49. Regulation (EC) No 443/2009 of the European Parliament and of the Council of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO2 emissions from light-duty vehicles [http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32009R0443 accessed 20.11.2014]
50. Regulation (EC) No 715/2007 of the European Parliament and of the Council of 20 June 2007 on type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information [http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32007R0715 accessed: 20.11.2014]
51. Segurado R, Krajačić G, Duić N, Alves L. Increasing the penetration of renewable energy resources in S. Vicente, Cape Verde. Appl. Energy 2011;88:466-472
52. Lund H, Kempton W. Integration of renewable energy into the transport and electricity sectors through V2G. Energy Policy 2008;36:3578-3587
53. Koopmans C. Bridging the energy efficiency gap using bottom up information in a top down demand model. Energy Economics, Volume 23, (2001), Pages 57-75
54. Suganthi L., Samuel A. A., Energy models for demand forecasting – A review, Renewable and sustainable energy reviews, Vol. 16, pp 1223-1240, 2012

55. Terry Barker, Paul Ekins, Tim Foxon. Macroeconomic effects of efficiency policies for energy-intensive industries: The case of the UK Climate Change Agreements, 2000–2010. Energy Economics, Volume 29, (2007), Pages 760-778
56. Deborah Wilson, Joel Swisher, Exploring the gap: Top-down versus bottom-up analyses of the cost of mitigating global warming, Energy Policy, Volume 21, Issue 3, March 1993, Pages 249-263.
57. IPCC Fourth Assessment Report: Climate Change 2007 (AR4), http://www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html [accessed 25.07.2013]
58. Daniel Wiesmann, Inês Lima Azevedo, Paulo Ferrão, John E. Fernández . Residential electricity consumption in Portugal: Findings from top-down and bottom-up models. Energy Policy, Volume 39, (2011), Pages 2772-2779
59. Patrícia Fortes, Rui Pereira, Alfredo Pereira, Júlia Seixas, Integrated technological-economic modeling platform for energy and climate policy analysis, Energy, Volume 73, 14 August 2014, Pages 716-730.
60. Detlef P. van Vuuren, Monique Hoogwijk, Terry Barker, Keywan Riahi, Stefan Boeters, Jean Chateau, Serban Scrieciu, Jasper van Vliet, Toshihiko Masui, Kornelis Blok, Eliane Blomen, Tom Kram, Comparison of top-down and bottom-up estimates of sectoral and regional greenhouse gas emission reduction potentials, Energy Policy, Volume 37, Issue 12, December 2009, Pages 5125-5139.
61. Henrik Klinge Jacobsen, Technological progress and long-term energy demand — a survey of recent approaches and a Danish case, Energy Policy, Volume 29, Issue 2, January 2001, Pages 147-157.
62. Iñigo Capellán-Pérez, Margarita Mediavilla, Carlos de Castro, Óscar Carpintero, Luis Javier Miguel, Fossil fuel depletion and socio-economic scenarios: An integrated approach, Energy, Available online 25 October 2014, ISSN 0360-5442, http://dx.doi.org/10.1016/j.energy.2014.09.063.
63. Christoph W. Frei, Pierre-André Haldi, Gérard Sarlos, Dynamic formulation of a top-down and bottom-up merging energy policy model, Energy Policy, Volume 31, Issue 10, August 2003, Pages 1017-1031.
64. N. Agya Utama, Andhy M. Fathoni, Mandau A. Kristianto, Benjamin C. McLellan, The End of Fossil Fuel Era: Supply-demand Measures through Energy Efficiency, Procedia Environmental Sciences, Volume 20, 2014, Pages 40-45

65. Subhes C. Bhattacharyya, Govinda R. Timilsina. Energy Demand Models for Policy Formulation: A Comparative Study of Energy Demand Models. The World Bank, Development Research Group - Environment and Energy Team, March 2009
66. Maxime Kleinpeter: Energy Planning and Policy, UNESCO Energy Engineering Learning Programme, John Wiley & Son Ltd, 1996
67. Clark W. Gellings: Demand-Side Management Planning, Fairmont Press, 1993
68. EU Climate and Energy Package for 2020 [http://ec.europa.eu/clima/policies/package/index_en.htm accessed 20.11.2014]
69. Trends and projections in Europe 2013-Tracking progress towards Europe's climate and energy targets until 2020, European Environment Agency [http://www.eea.europa.eu/publications/trends-and-projections-2013/full-report-ghg-trends-and-1 accessed 20.11.2014]
70. Mapping renewable energy pathways till 2020 – EU road map, EREC [http://www.repap2020.eu/fileadmin/user_upload/Roadmaps/EREC-roadmap-V4_final.pdf accessed 20.11.2014]
71. Energy 2020 - A strategy for competitive, sustainable and secure energy, European Commission, 2010 [http://ec.europa.eu/energy/energy2020/energy2020_en.htm accessed 20.11.2014]
72. Overview of CO2 based motor vehicle taxes in the EU – European automobile manufacturers associations [www.acea.be/uploads/publications/CO2_tax__overview_2013.pdf accessed 20.11.]
73. Energy efficiency Directive – Article 7 (Monitoring energy savings), http://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive [accessed 25.02.2015]
74. RE-thinking 2050; A 100% Renewable vision for the EU, EREC 2010 [http://ec.europa.eu/digital-agenda/futurium/en/content/re-thinking-2050-100-renewable-energy-vision-european-union accessed 20.11.2014]
75. Ian Richardson, Murray Thomson, David Infield, Conor Clifford. Domestic electricity use: A high-resolution energy demand model. Energy and Buildings, Volume 42, (2010), Pages 1878–1887
76. I.J.Lu, Charles Lewis, Sue J. Lin. The forecast of motor vehicle, energy demand and CO2 emission from Taiwan s road transportation sector. Energy Policy, Volume 37, (2009), Pages 2952-2961

77. Joakim Widén, Ewa Wäckelgĺrd. A high-resolution stochastic model of domestic activity patterns and electricity demand. Applied Energy, Volume 87, (2010), Pages 1880–1892
78. Huang Y., Bor Y. J., Peng C. Y., Long-term forecast of Taiwan's energy supply and demand: LEAP model application, Energy policy, Volume 39, (2011), Pages 6790-6803
79. Amirnekooei K., Ardehali M. M., sadri A., Integrated resources planning for Iran: development of reference energy system, forecast, and long-term energy-environment plan, Energy, Volume 46, (2012), Pages 374-385
80. Fleiter T., Worrell E., Eichhmmer W., Barriers to energy efficiency in industrial bottom up energy demand models – A review, Renewable and sustainable energy reviews, Vol. 15, pp 3099-3111, 2011
81. Gouveia J. P., Fortes P., Seixas J., Projections of energy services demand for residential buildings: Insights from a bottom up methodology, Energy, Vol. 47, pp 430-442, 2012
82. Rout U. K., Vol A., Singh A., Fahl U., Blesl M., Gallachoir B. P. O., Energy and emissions forecast of China over a long-time horizon, Energy, Vol. 36, pp 1-11, 2011
83. Bhattacharyya S. C., Timilsina G. R., Energy demand models for policy formulation, Policy research working paper, World Bank, 2009
84. Vuk B, Vukman S, Karan M, Fabek R, Zivkovic S, Maricevic M, et al. Annual energy report – Energy in Croatia. Zagreb, Croatia: Ministry of Economy, Labour and entrepreneurship; 2009.
85. Schneider DR, Duić N, Bogdan Ž. Mapping the potential for decentralized energy generation based on renewable energy sources in the Republic of Croatia. Energy 2007;32:1731-1744
86. Aste N, Adhikari RS, Buzzetti M. Beyond the EPBD: The low energy residential settlement Borgo Solare. Appl. Energy 2010;87:629-642
87. Popescu D, Bienert S, Schützenhofer C, Boazu R. Impact of energy efficiency measures on the economic value of buildings. Appl. Energy 2012;89:454-463
88. Duić N, Juretić F, Zeljko M, Bogdan Ž. Croatia energy planning and Kyoto Protocol. Energy Policy 2005;33:1003-1010
89. Peeters L, de Dear R, Hensen J, D'haeseleer W. Thermal comfort in residential buildings: Comfort values and scales for building energy simulation. Appl. Energy 2009;86:772-780

90. Shimoda Y, Yamaguchi Y, Okamura T, Taniguchi A, Yamaguchi Y. Prediction of greenhouse gas reduction potential in Japanese residential sector by residential energy end-use model. Appl. Energy 2010;87:1944-1952
91. Murata A, Kondou Y, Hailin M, Weisheng Z. Electricity demand in the Chinese urban household-sector. Appl. Energy 2008;85:1113-1125
92. Swan LG, Ugursal VI. Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. Renew and Sust Energy Rev 2009;13:1819-1835
93. Wan KSY, Yik FHW. Representative building design and internal load patterns for modelling energy use in the residential buildings in Hong Kong. Appl. Energy 2004;77:69-85
94. Aydinalp M, Ugursal VI, Fung AS. Modelling of the space and domestic hot-water heating energy-consumption in the residential sector using neural networks. Appl. Energy 2004;79:159-178
95. Rose Murphy, Mark Jaccard, Energy efficiency and the cost of GHG abatement: A comparison of bottom-up and hybrid models for the US, Energy Policy, Volume 39, Issue 11, November 2011, Pages 7146-7155
96. International Energy Agency – World Energy Model , www.iea.org/weo/model.asp [accessed 22.02.12]
97. Kannan R, Strachan N. Modelling the UK residential energy sector under long-term decarbonisation scenarios: Comparison between energy systems and sectoral modelling approaches. Appl. Energy 2009;86:416-428
98. Marszal AJ, Heiselberg P, Bourrelle JS, Musall E, Voss K, Sartori I et al. Zero energy building – A review of definitions and calculation methodologies. Energy and buildings 2011;43:971-979
99. Eoin Ó Broin, Érika Mata, Anders Göransson, Filip Johnsson. The effect of improved efficiency on energy savings in EU-27 buildings. Energy, Volume 57, (2013), Pages 134–148
100. João Pedro Gouveia, Patrícia Fortes, Júlia Seixas. Projections of energy services demand for residential buildings: Insights from a bottom-up methodology. Energy, Volume 47, (2012), Pages 430–442
101. M. Kavgic, A. Mavrogianni, D. Mumovic, A. Summerfield, Z. Stevanovic, M. Djurovic-Petrovic, A review of bottom-up building stock models for energy

consumption in the residential sector, Building and Environment, Volume 45, Issue 7, July 2010, Pages 1683-1697.

102. Irsag, Bojan; Pukšec, Tomislav; Duić, Neven. Long term energy demand projection and potential for energy savings of Croatian tourism-catering trade sector. Energy, Volume 48, (2012), Pages 398-405

103. Mathiesen BV, Lund H, Karlsson K. 100% Renewable energy systems, climate mitigation and economic growth. Appl. Energy 2011;88:488-501

104. Xiaoyu Y, Crookes RJ. Reduction potentials of energy demand and GHG emissions in China's road transport sector Energy Policy 2009;37:658-668

105. Adaptation and upgrade of Croatian Energy strategy – Green book. Zagreb, Croatia: Ministry of Economy, Labour and entrepreneurship, 2008.

106. Sa'ad S. Improved technical efficiency and exogenous factors in transportation demand for energy: An application of structural time series analysis to South Korean dana. Energy 2010;35:2745-2751

107. Al-Ghandoor A, Samhouri M, Al-Hinti I, Jaber J, Al-Rawashdeh M. Projection of future transport energy demand of Jordan using adaptive neuro-fuzzy technique. Energy 2012;38:128-135

108. Limanond T, Jomnonkwao S, Srikaew A. Projection of future transport energy demand of Thailand. Energy Policy 2011;39:2754-2763

109. Yu S, Zhu K. A hybrid procedure for energy demand forecasting in China. Energy 2012;37:396-404

110. Zhang S, Jiang K, Liu D, Passenger transport modal split based on budgets and implication for energy consumption: Approach and application in China. Energy Policy 2007;35:4434-4443

111. Parikh KS, Karandikar V, Rana A, Dani P. Projecting India's energy requirements for policy formulation. Energy 2009;34:928-941

112. Eom J, Schipper L. Trends in passenger transport energy use in South Korea. Energy Policy 2010;38:3598-3607

113. Bauer M, Mar E, Elizalde A. Transport and energy demand in Mexico: the personal income shock. Energy Policy 2003;31:1475-1480

114. Turton H. Sustainable global automobile transport in the 21st century: An integrated scenario analysis. Technol. Forecasting and Social Change 2006;73:607-629

115. Kyle P, Kim SH. Long-term implications of alternative light-duty vehicle technologies for global greenhouse gas emissions and primary energy demands. Energy Policy 2011;39:3012-3024

116. Mark Jaccard, Rose Murphy, Nic Rivers, Energy–environment policy modeling of endogenous technological change with personal vehicles: combining top-down and bottom-up methods, Ecological Economics, Volume 51, Issues 1–2, 1 November 2004, Pages 31-46.

117. Juan Carlos Solís, Claudia Sheinbaum. Energy consumption and greenhouse gas emission trends in Mexican road transport. Energy for Sustainable Development, Volume 17, (2013), Pages 280–287

118. Christian Brand, Martino Tran, Jillian Anable, The UK transport carbon model: An integrated life cycle approach to explore low carbon futures, Energy Policy, Volume 41, February 2012, Pages 107-124

119. Bačelić Medić, Zlatko; Pukšec, Tomislav; Mathiesen, Brian Vad; Duić, Neven. Modelling energy demand of Croatian industry sector. // International Journal of Environment and Sustainable Development. 13 (2014) , 1; 74-92 (članak, znanstveni).

120. Gondia Sokhna Seck, Gilles Guerassimoff, Nadia Maïzi. Heat recovery with heat pumps in non-energy intensive industry: A detailed bottom-up model analysis in the French food & drink industry. Applied Energy, Volume 111, (2013), Pages 489–504.

121. Tobias Fleiter, Ernst Worrell, Wolfgang Eichhammer, Barriers to energy efficiency in industrial bottom-up energy demand models—A review, Renewable and Sustainable Energy Reviews, Volume 15, Issue 6, August 2011, Pages 3099-3111.

122. Zongguo Wen, Fanxin Meng, Min Chen, Estimates of the potential for energy conservation and CO2 emissions mitigation based on Asian-Pacific Integrated Model (AIM): the case of the iron and steel industry in China, Journal of Cleaner Production, Volume 65, 15 February 2014, Pages 120-130.

123. Wenying Chen, Xiang Yin, Ding Ma, A bottom-up analysis of China's iron and steel industrial energy consumption and CO2 emissions, Applied Energy, Available online 8 July 2014, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2014.06.002.

124. Lorna A. Greening, Gale Boyd, Joseph M. Roop, Modeling of industrial energy consumption: An introduction and context, Energy Economics, Volume 29, Issue 4, July 2007, Pages 599-608

125. Yophy Huang, Yunchang Jeffrey Bor, Chieh-Yu Peng, The long-term forecast of Taiwan's energy supply and demand: LEAP model application, Energy Policy, Volume 39, Issue 11, November 2011, Pages 6790-6803

126. J. Reichl, A. Kollmann The baseline in bottom-up energy efficiency and saving calculations – a concept for its formalisation and a discussion of relevant options. Applied Energy, Volume 88, (2011), Pages 422–431

127. Banister D, Hickman R. Transport futures: Thinking the unthinkable. Transport Policy 2012, http://dx.doi.org/10.1016/j.tranpol.2012.07.005

128. Sofia Simoes, Patrícia Fortes, Júlia Seixas, Gjalt Huppes, Assessing effects of exogenous assumptions in GHG emissions forecasts – a 2020 scenario study for Portugal using the Times energy technology model, Technological Forecasting and Social Change, Available online 12 October 2014, ISSN 0040-1625, http://dx.doi.org/10.1016/j.techfore.2014.09.016.

129. Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency [http://eur-lex.europa.eu/legal-content/en/TXT/?uri=celex:32012L0027 accessed 14.11.2014]

130. D. Dineen, B.P. Ó Gallachóir, Modelling the impacts of building regulations and a property bubble on residential space and water heating, Energy and Buildings, Volume 43, Issue 1, January 2011, Pages 166-178.

131. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources [http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32009L0028 accessed 17.04.2014]

132. Tomislav Pukšec, Brian Vad Mathiesen, Tomislav Novosel, Neven Duić, Assessing the impact of energy saving measures on the future energy demand and related GHG (greenhouse gas) emission reduction of Croatia, Energy, Volume 76, 1 November 2014, Pages 198-209

133. Hong L., Lund H., Moller B., The importance of flexible power plant operation for Jiangsu's wind integration , Energy, Vol. 42, pp 499-507, 2012

134. Busuttil A., Krajačić G., Duić N., Energy scenarios for Malta, International journal of hydrogen energy, Vol. 33, pp 4235-4246, 2008

135. Huang Y., Bor Y. J., Peng C. Y., Long-term forecast of Taiwan's energy supply and demand: LEAP model application, Energy policy, Vol. 39, pp 6790-6803, 2011

136. Amirnekooei K., Ardehali M. M., sadri A., Integrated resources planning for Iran: development of reference energy system, forecast, and long-term energy-environment plan, Energy, Vol. 46, pp 374-385, 2012

137. José Baltazar Salgueirinho Osório De Andrade Guerra, Luciano Dutra, Norma Beatriz Camisão Schwinden, Suely Ferraz de Andrade, Future scenarios and trends in energy generation in brazil: supply and demand and mitigation forecasts, Journal of Cleaner Production, Available online 2 October 2014, ISSN 0959-6526, http://dx.doi.org/10.1016/j.jclepro.2014.09.082 .

138. Ullash K. Rout, Alfred Voβ, Anoop Singh, Ulrich Fahl, Markus Blesl, Brian P. Ó Gallachóir, Energy and emissions forecast of China over a long-time horizon, Energy, Volume 36, Issue 1, January 2011, Pages 1-11.

139. Jovanovic M., Afgan N., Bakic V., An analytical method for the measurement of energy system sustainability in urban areas, Energy, Vol. 35, pp 3909-3920, 2010

140. Hainoun A., Seif-Eldin M. K., Almoustafa S., Analysis of the Syrian long-term energy and electricity demand projection using end-use methodology, Energy policy, Vol. 34, pp 1958-1970, 2006

141. Energy performance of buildings- calculation of energy use for space heating and cooling ISO 13790. Second edition; 2008, http://www.iso.org/iso/catalogue_detail.htm?csnumber=41974 [accessed 12.02.12]

142. Energy Efficiency Indicators in Europe- ODYSSEE-MURE; 2010. <www.odyssee-indicators.org> [accessed 15.04.11]

143. Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies - Part 3-1: Domestic hot water systems, characterisation of needs – DIN EN 15316-3-1; 2008

144. Connolly D, Lund H, Mathiesen BV, Leahy M. The first step towards a 100% renewable energy-system for Ireland. Appl. Energy 2011;88:502-507

145. Croatian Ministry of tourism, http://www.mint.hr/default.aspx?id=371, 2014 [accessed 01.12.2014]

146. Madeleine McPherson, Bryan Karney, Long-term scenario alternatives and their implications: LEAP model application of Panama′s electricity sector, Energy Policy, Volume 68, May 2014, Pages 146-157

147. COMMEND (COMMunity for ENergy environment & Development) http://www.energycommunity.org/default.asp?action=47 [accessed 06.02.2015]

148. R. Ghanadan, J.G. Koomey, Using energy scenarios to explore alternative energy pathways in California, Energy Policy, Volume 33, 2005, pp. 1117–1142

149. Santiago Bautista, A sustainable scenario for Venezuelan power generation sector in 2050 and its costs, Energy Policy, Volume 44, May 2012, Pages 331-340

150. Sooyoung Jun, Seungmoon Lee, Jin-Won Park, Suk-Jae Jeong, Ho-Chul Shin, The assessment of renewable energy planning on CO2 abatement in South Korea, Renewable Energy, Volume 35, Issue 2, February 2010, Pages 471-477

151. Aumnad Phdungsilp, Integrated energy and carbon modeling with a decision support system: Policy scenarios for low-carbon city development in Bangkok, Energy Policy, Volume 38, Issue 9, September 2010, Pages 4808-4817

152. Yacob Mulugetta, Nathinee Mantajit, Tim Jackson, Power sector scenarios for Thailand: An exploratory analysis 2002–2022, Energy Policy, Volume 35, Issue 6, June 2007, Pages 3256-3269

153. Dacheng Liu, XiaoouYang, Xianchun Tian, Ruihao Wu, Li Wang, Study on integrated simulation model of economic, energy and environment safety system under the low-carbon policy in Beijing, Procedia Environmental Sciences, Volume 5, 2011, Pages 120-130

154. Wenjia Cai, Can Wang, Ke Wang, Ying Zhang, Jining Chen, Scenario analysis on CO2 emissions reduction potential in China's electricity sector, Energy Policy, Volume 35, Issue 12, December 2007, Pages 6445-6456

155. Leila Dagher, Isabella Ruble, Modeling Lebanon’s electricity sector: Alternative scenarios and their implications, Energy, Volume 36, Issue 7, July 2011, Pages 4315-4326

156. Irsag B., Energy demand side modelling of Croatian tourist-catering trade sector based on technological, legal and financial mechanisms, Graduate thesis, Zagreb 2011

157. Tehnički propis o racionalnoj uporabi energije i toplinskoj zaštiti u zgradama, Ministry of construction and physical planning, http://www.mgipu.hr/default.aspx?id=12841 [accessed 20.03.2015]

158. METEONORM Software, http://meteonorm.com/ [accessed 25.02.2015]

159. Croatian bureau of statistics – Yearly statistical reports for the year 2012, http://www.dzs.hr/Hrv_Eng/ljetopis/2012/sljh2012.pdf [accessed 25.11.2014]

160. McKinsey – Group of authors, Drive, the future of automotive power, http://www2.autoassembly.mckinsey.com/html/resources/publication/b_DRIVE.asp [accessed 26.02.2015]

161. H. Lund, A.N. Andersen, P.A. Østergaard, B.V. Mathiesen, D. Connolly, From electricity smart grids to smart energy systems – a market operation based approach and understanding, Energy, 42 (2012), pp. 96–102

162. B.V. Mathiesen, H. Lund, P. Nørgaard, Integrated transport and renewable energy systems, Utilities Policy, 16 (2008), pp. 107–116

163. Biying Yu, Junyi Zhang, Akimasa Fujiwara, Evaluating the direct and indirect rebound effects in household energy consumption behavior: A case study of Beijing, Energy Policy, Volume 57, June 2013, Pages 441-453

164. Eoin Ó Broin, Jonas Nässén, Filip Johnsson, The influence of price and non-price effects on demand for heating in the EU residential sector, Energy, Volume 81, 1 March 2015, Pages 146-158

165. Pil Seok Kwon, Poul Østergaard, Assessment and evaluation of flexible demand in a Danish future energy scenario, Applied Energy, Volume 134, 1 December 2014, Pages 309-320

166. Peter D. Lund, Juuso Lindgren, Jani Mikkola, Jyri Salpakari, Review of energy system flexibility measures to enable high levels of variable renewable electricity, Renewable and Sustainable Energy Reviews, Volume 45, May 2015, Pages 785-807

167. Danish Energy Agency, http://www.ens.dk/en/policy/danish-climate-energy-policy [accessed 20.03.2015]

6 BIOGRAPHY

TOMISLAV PUKŠEC dipl.ing. was born on the 27th of July 1983 in Zagreb, Croatia. In 2001 he finished high school education at the Vrbovec Gymnasium and started his studies at the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, which he finished in 2008. Since 2009 he has been employed at the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, at the Department of Power Engineering, Energy and Environment as a research assistant and PhD student. He is working on various projects dealing with energy efficiency and renewable energy sources. He worked on five IEE projects (GERONIMO, GERONIMO2, Flick the switch, ERASME and E-SEAP) and is currently working on two ongoing IEE projects (STRATEGO and BEAST), two FP7 projects (Joriew and DISKNET), one IPA project (ADRIACOLD) and one Horizon 2020 project (Bin2Grid). He also worked on two national projects financed by the Croatian science foundation (iRESEV and NEP-HR (which he coordinated through PhD students programme)).

Since 2010 he has been working on the national scientific project: Smart energy storage for sustainable development of energy systems, financed by the Ministry of Science, Education and Sport of the Republic of Croatia.

He has been awarded two scientific scholarships; Croatian science foundation (Aalborg University) and Erasmus Mundus for PhD students (American University of Beirut). He is the recipient of the award given by "The Society of University Teachers, Scholars and Other

Scientists in Zagreb” for The Best Young Scientists and Artists in the year 2012 (category: technical field).

He is the author of 32 scientific papers, of which 13 in scientific journals (CC/SCI). His Scopus *h*-index is 4. He reviews papers for Energy efficiency, Energy and JSDEWES journals. Since 2009 he has been involved in the organization of SDEWES conferences and from 2012 he serves as a supervisory board member of the International Centre for Sustainable development of Energy, Water and Environment Systems.

List of publish scientific journal papers:

- Cerovac, Tin; Ćosić, Boris; Pukšec, Tomislav; Duić, Neven. Wind energy integration into future energy systems based on conventional plants – The case study of Croatia. // *Applied energy*. 135 (2014) ; 643-655 (journal article).
- Novosel, Tomislav; Ćosić, Boris; Krajačić, Goran; Duić, Neven; Pukšec, Tomislav; Mohsen, S. Mousa; Ashhab, S. Moh'd; Ababneh, K. Amer. The influence of reverse osmosis desalination in a combination with pump storage on the penetration of wind and PV energy: A case study for Jordan. // *Energy (Oxford)*. 76 (2014) ; 73-81 (journal article)
- Pukšec, Tomislav; Mathiesen, Brian Vad; Novosel, Tomislav; Duić, Neven. Assessing the impact of energy saving measures on the future energy demand and related GHG emission reduction of Croatia. // *Energy (Oxford)*. 76 (2014) ; 198-209 (journal article)
- Pukšec, Tomislav; Krajačić, Goran; Lulić, Zoran; Mathiesen, Brian Vad; Duić, Neven. Forecasting long-term energy demand of Croatian transport sector. // *Energy (Oxford)*. 57 (2013) ; 169-176 (journal article)
- Pukšec, Tomislav; Mathiesen, Brian Vad; Duić, Neven. Potentials for energy savings and long term energy demand of Croatian households sector. // *Applied energy*. 101 (2013) , SI; 15-25 (journal article)
- Irsag, Bojan; Pukšec, Tomislav; Duić, Neven. Long term energy demand projection and potential for energy savings of Croatian tourism-catering trade sector. // *Energy (Oxford)*. 48 (2012) , 1; 398-405 (journal article)
- Pukšec, Tomislav; Duić, Neven. Economic viability and geographic distribution of centralized biogas plants: case study Croatia. // *Clean technologies and environmental policy*. 14 (2012) , 3; 427-433 (journal article)

- Pukšec, Tomislav; Duić, Neven. Biogas Potential in Croatian Farming Sector. // *Strojarstvo*. 52 (2010) , 4; 441-448 (journal article)
- Bačelić Medić, Zlatko; Pukšec, Tomislav; Mathiesen, Brian Vad; Duić, Neven. Modelling energy demand of Croatian industry sector. // *International Journal of Environment and Sustainable Development*. 13 (2014) , 1; 74-92 (journal article)
- Bjelic, Ilija Batas; Skokljev, Ivan; Pukšec, Tomislav; Krajačić, Goran; Duić, Neven. Integrating the flexibility of the average Serbian consumer as a virtual storage option into the planning of energy systems. // *Thermal science*. 18 (2014) , 3; 743-754 (journal article)
- Novosel, Tomislav; Gašparović, Goran; Ćosić, Boris; Mustafa, Manal; Krajačić, Goran; Pukšec, Tomislav; Duić, Neven. Integration of Desalination and Renewables, a Demonstration of the Desalination Module in the H2RES Model: Case Study for Jordan. // *Chemical engineering transactions*.39 (2014) ; 335-360 (journal article)
- Novosel, Tomislav; Pukšec, Tomislav; Duić, Neven. Economic Viability and Environmental Impact of Centralized Biogas Plants in Croatia. // *Computer Aided Chemical Engineering*. 33 (2014) ; 1867-1872 (journal article)
- Pukšec, Tomislav; Duić, Neven. Geographic distribution and economic potential of biogas from Croatian farming sector. // *Chemical Engineering Transactions*. 25 (2011) ; 899-904 (journal article)