Electronic Supplementary Information

Hidden Intermediate Activation: A Concept to Elucidate the Reaction Mechanism of the Schmittel Cyclization of Enyne-Allenes

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1. Computational Details

The calculations were made using the Density Functional Theory (DFT) study to consider the effects of exchange and correlation electronics in molecular systems. The hybrid GGA B3LYP functional[1,2] combined with the 6-311+G(d,p) basis was used for the stationary points. This functional was chosen because it is highly recommended for this type of reaction, fully agreeing with experimental data. [3,4] In addition, this functional was compared with high accuracy methods, such as SCS-MP2[5] and DLPND-CCSD(T)[6] for both activation and reaction energies (see Benchmark Study section). The harmonic vibrational analysis was carried out to confirm reactants and products as a minimum on the potential energy surface and the transition state (TS) as a first-order saddle point with a single negative eigenvalue on its Hessian matrix.[7] Transition state structures were related to reactants and products using the intrinsic reaction coordinate (IRC).[8–10] All calculations were performed in Gaussian 16 (G16)[11] software package, and the 3D and 2D potential energy surfaces (PESs) were optimized in the Orca 4.0.0.2 [12] software package by scan method. Ab-initio molecular dynamics were carried out using the Born-Oppenheimer Molecular Dynamics (BOMD) procedure implemented in Gaussian 16 software at the uB3LYP/6-31g(d,p) level of theory. It was considered 256 trajectories in each reaction at 298K with a step-size of 0.25 $amu^{1/2}$bohr (0.53 fs approx.). The simulations were performed up to 4000 steps (2.12 ps approx.); however, due to the possibility that the zero-point-energy in the normal modes leak out, we have considered meaningful trajectories up to 540 fs. Therefore, any trajectory that reached product in a period larger than 540 fs will be considered as unfinished. Force constants were updated every 12 steps. All trajectories were propagated using initial atomic position and velocities obtained by performing a normal mode sampling to the TS structure at 298 K in the forward and reverse direction. An inter-nuclear distance between the C2 and C6 threshold of 3.1 Å was used as the termination criterion of the reverse direction trajectories. Trajectories were classified into three groups: (i) *productive* if the reactant is reached in one direction and the product is formed in the other one, (ii) *unproductive* if the reactant or product is not formed in any of both directions, and (iii) *recrossing* if the trajectory starts and finish at the same structure of the PES (reactant or product).

All calculations were performed using an unrestricted protocol due to the biradical character of some structures. The visualization and generation of molecular structures were performed with the Chemcraft[13] program, and the figures were generated with the CYLview[14] software.

2. Benchmark study

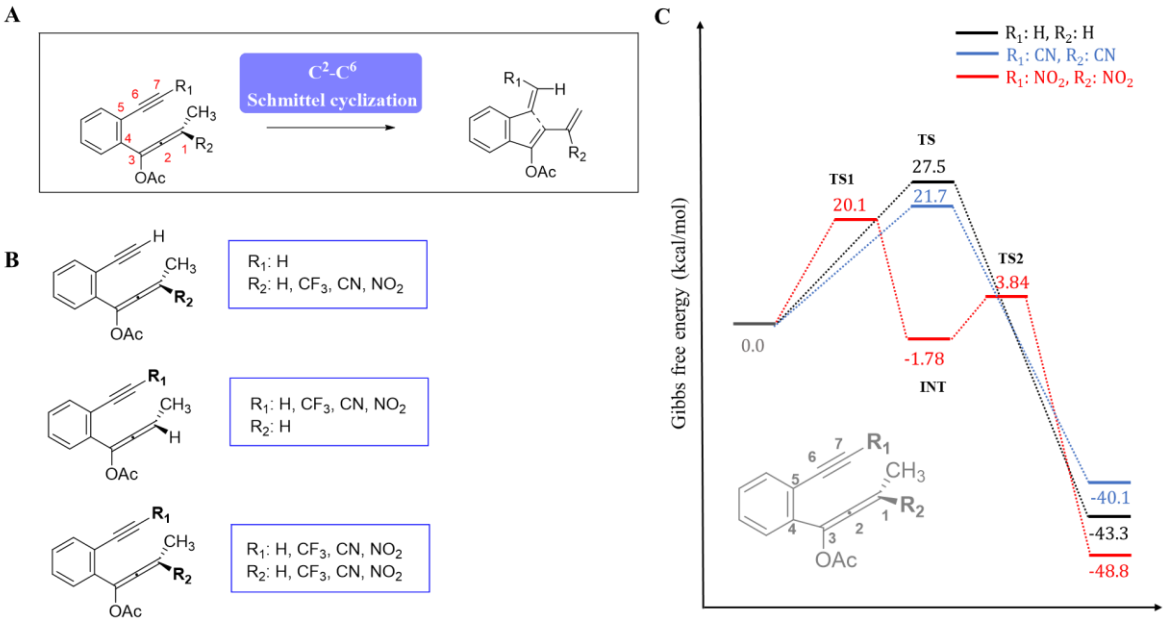
The Benchmark study was a performance for DFT functionals, where three functionals were investigated: one-hybrid-GGA: B3LYP [1,15] (with and without dispersion correction), a hybrid-meta-GGA: M06-2X [16], and a long-range corrected hybrid-GGA: ωB97X-D3 [17], which were compared with the domain-based local pair-natural orbital DLPNO-CCSD(T) [6] and SCS-MP2 method in Orca 4.0.0.2 [12] program.

The results are shown in Table S1, indicating that the B3LYP functional without dispersion correction is more comparable with the high-accuracy DLPNO-CCSD(T) and SCS-MP2 methods in both the activation energy and the reaction energy. Additionally, the B3LYP functional showed to be cheaper computationally.

Table S1: Reaction energy ($\Delta E°$), activation energy ($\Delta E^{\neq}$), and time for one process that takes each method to complete the calculation.

Method	$\Delta E°$ (kcal/mol)	$\Delta E^{\neq}$ (kcal/mol)	Time for one processor (minutes)
B3LYP	-50.9	27.4	2916
B3LYP-D3	-49.3	20.3	3238
M06-2X	-48.2	30.1	1168
ωB97X-D3	-50.9	30.5	7728
DLPNO-CCSD(T)	-50.8	28.7	1408
SCS-MP2	-49.3	26.7	388608

3. Reaction mechanism of the C^2-C^6 enyne-allene cyclization



Scheme S1: A) C^2-C^6 cyclization of enyne-allenes reaction, known as Schmittel reaction. B) three substitution patterns were studied. C) Gibbs free energy diagram for the three cyclizations studied.

Three electron-withdrawing substituents were considered: CF_3, CN, and NO_2, in R1 and R2 positions in enyne–allene (Scheme S1). Three substitutions patterns were studied; (i) R1: H, R2: H/CF_3/CN/NO_2; (ii) R1: H/CF_3/CN/NO_2, R2: H, and (iii) R1, R2: H/CF_3/CN/NO_2, this last one as doubly substituted with the same group/atom. Based on the reaction force constant profiles,[18,19] the mechanism of all reactions has been classified as either synchronous or asynchronous. On the one hand, for the first substitution pattern, it was found that the mechanism follows a one-step pathway involving simultaneous C2-C6 and C7-H bond stretching. On the other hand, a transition from synchronous to asynchronous was found when the substituent changed from H to NO_2, fully asynchronous when R2 was replaced with the NO_2 group. For the second substitution pattern, the pathway changes from one-step (synchronous or asynchronous) to stepwise as the EWG power of the substituent increases. Incorporating attractor groups entails a more substantial intermediate stabilization for the third substitution pattern, so this pattern is better suitable for assessing the DMIS.

Figure S1-A shows the representation of the mechanism that reactions follow with the three substituents, where non-substituted enyne–allene reaction takes place by a one-step pathway (black line). The shape of the energy profile of this system (Fig. S1-B) is characteristic of that taking place in one elemental step, where the transition state for this mechanism presents bond distances of 2.04 Å and 1.63 Å for C2-C6 and C7-H (Fig. S1-B), respectively, which are the bonds that are forming in the reaction, being these chemical events fully coupled). In the case of enyne–allenes substituted with NO_2 groups, both chemical events are decoupled, generating a stepwise mechanism (Fig. S1). The first transition state involves the C2-C6 bond stretching as vibrational mode, leading to the intermediate formation, and in the latter, the hydrogen transfer takes place. The intermediate formation is the rate-determining step in this case. A different situation is found with the CN group (blue line in Fig. S1-A), where the shape of the energy profile is unusual (Fig. S1-B), presenting a shoulder after the transition state. This shoulder gives enough information to think that the mechanism is different from enyne–allene without substituents.

On the other hand, if we pay attention to bond distances at the TS structure, it is found that the bond formation is partially uncoupling, where the C7-H bond, related to the hydrogen transfer, increases to 2.28 Å (Fig. S1-C), accounting for the partial decoupling of both chemical events. Additionally, from the DMIS perspective, the shoulder can be related to the appearance of a partially hidden intermediate. In this way, it is possible to suggest that cyano groups in R1 and R2 stabilize the intermediate enough to appear in the energy profile, but it is not enough to appear as a formal intermediate (local minimum). Finally, the red line represents the substitution with the nitro group. In this case, the reaction's pathway is stepwise, where two transition states are found. The first is related to C2-C6 bond formation and the second to H-shift. The first transition state shows bond distances of 1.99 Å and 3.51 Å, which indicates the total decoupling of both events. Therefore, the nitro group in R1 and R2 generates a complete stabilization of the intermediate, resulting in the appearance of an explicit intermediate in the PES.

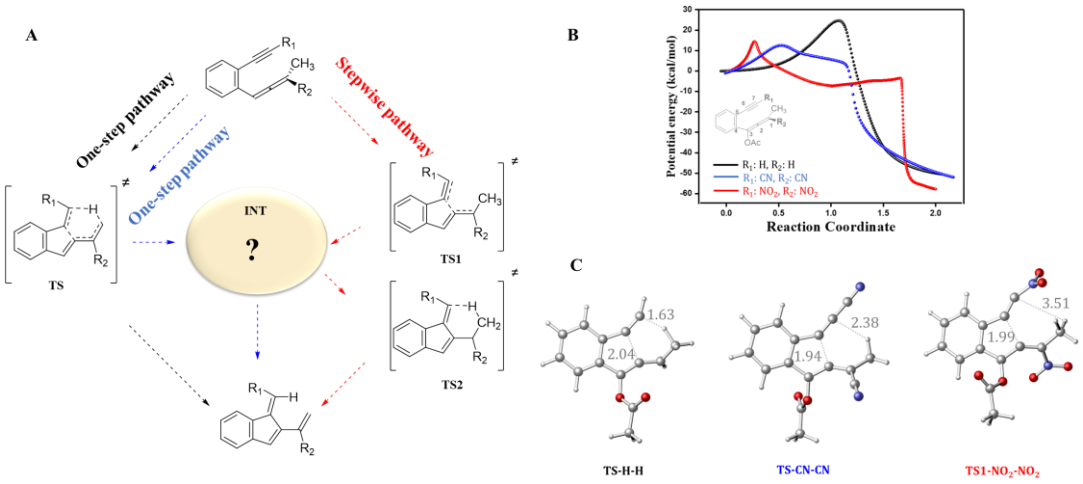


Figure S1: A) Schematic representation of one-step and stepwise mechanisms. B) Potential energy profile for three reactions studied (energy is in kcal/mol). C) Transition state structures for the three reactions (bond distances are in Å).

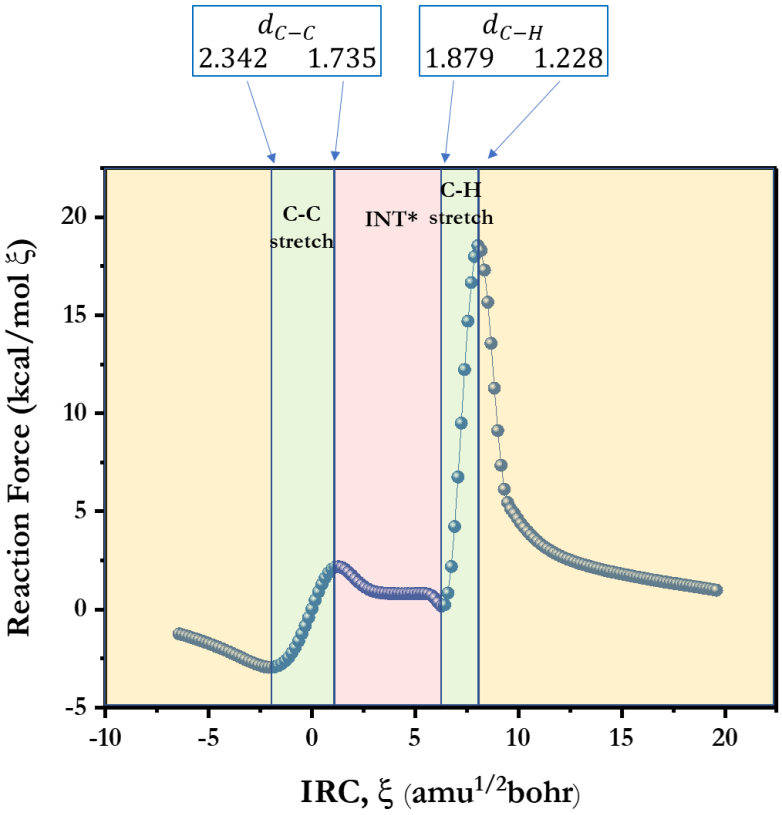


Figure S2: Reaction Force Analysis (RFA)[20,21] of the IRC for the title reaction of the system with CN substituents. The RFA allowed the definition of the borders of the transition state zones.

4. Substitution position study with electron-withdrawing groups

Case 1

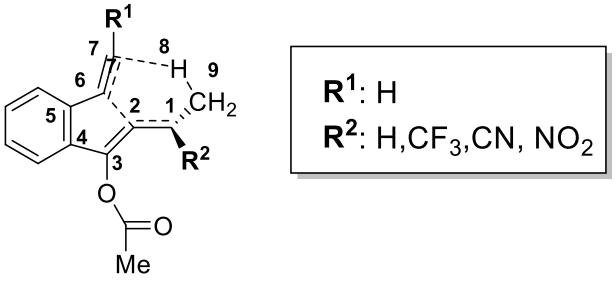


Table S2: Activation energy ($\Delta E^{\neq}$), reaction energy (ΔE^{o}), and mechanism type for case study 1 in UB3LYP/6-31G(d,p). The R1 position is unsubstituted; while the R2 position is substituted with CF_3, CN, and NO_2 electron-withdrawing groups, the energies value is in kcal/mol.

System	$\Delta E^{\neq}$	ΔE^{o}	Mechanism
H-H	24.61	-50.46	Synchronous one-step
H-CF_3	23.39	-50.21	Synchronous one-step
H-CN	21.92	-46.08	Synchronous one-step
H-NO_2	17.82	-54.65	Asynchronous one-step

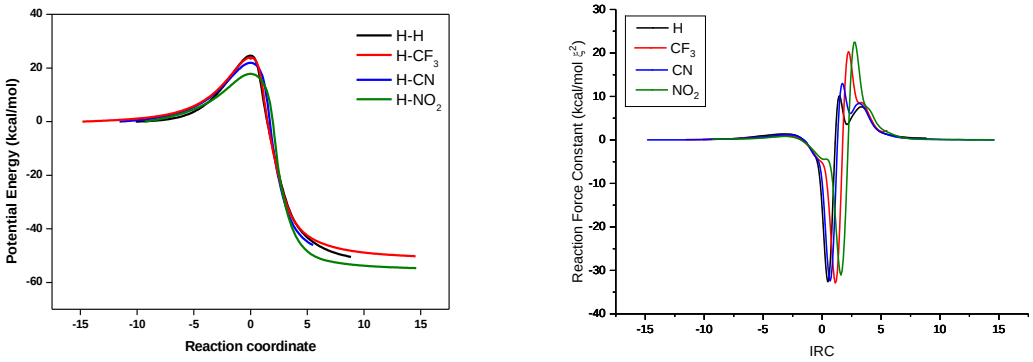


Figure S3: Potential energy (left) and reaction force constant (right) profiles for case study 1 in UB3LYP/6-31G(d,p). The R1 position is unsubstituted, while the R2 position is substituted with CF_3, CN, and NO_2 electron-withdrawing groups.

Case 2

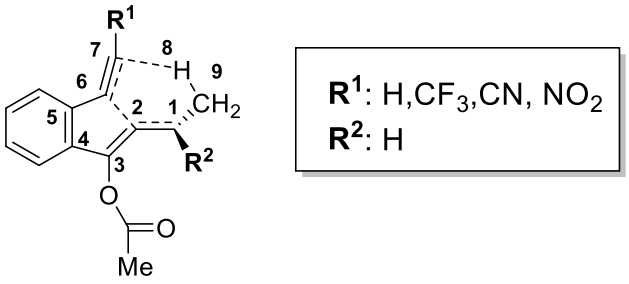


Table S3: Activation energy ($\Delta E^{\neq}$), reaction energy (ΔE^{o}), and mechanism type for case study 2 in UB3LYP/6-31G(d,p). The R1 position is substituted with CF_3, CN, and NO_2 electron-withdrawing groups, while the R2 position is unsubstituted. The energy value is in kcal/mol.

System	$\Delta E^{\neq}$	ΔE^{o}	Mechanism
H-H	24.61	-50.46	Synchronous one-step
CF_3-H	22.96	-47.71	Synchronous one-step
CN-H (TS1)	21.26	-45.06	Stepwise
NO_2-H	18.71	-55.61	Asynchronous one-step

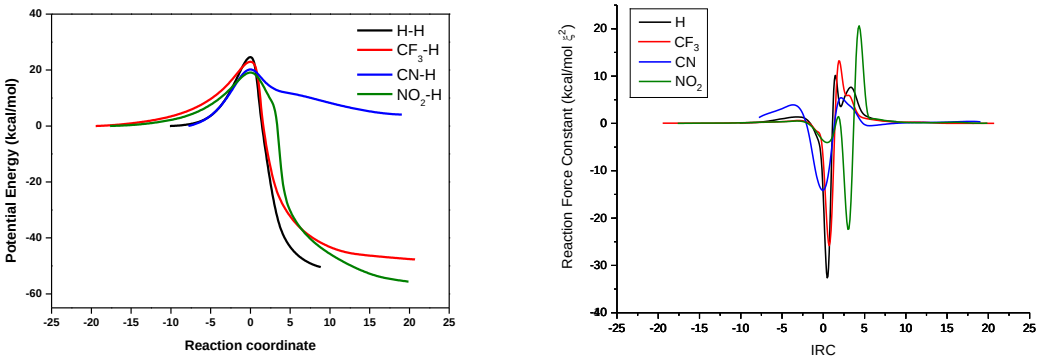


Figure S4. Potential energy (left) and reaction force constant (right) profiles for case study 2 in UB3LYP/6-31G(d,p). The R1 position is substituted with CF_3, CN, and NO_2 electron-withdrawing groups, while the R2 position is unsubstituted.

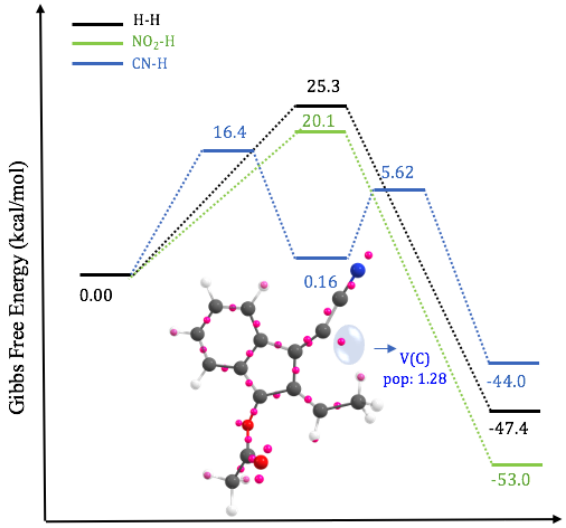


Figure S5: Gibbs free energy Diagram for case study 2 in UB3LYP/6-31G(d,p). The R1 position is substituted with CF_3, CN, and NO_2 electron-withdrawing groups, while the R2 position is unsubstituted. Basin attractors of the Electron Localization Function (ELF) for the intermediate (R1: H, R2: CN) and the population of the carbon basin are highlighted in blue.

Case 3

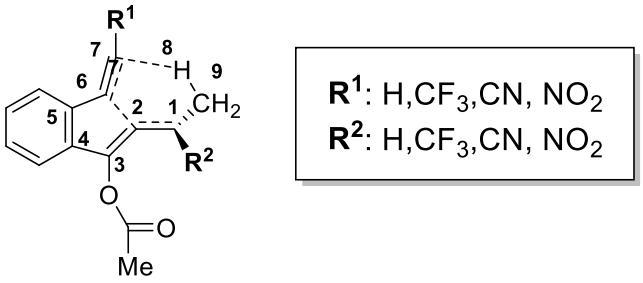


Table S4: Activation energy ($\Delta E^{\neq}$), reaction energy (ΔE^{o}), and mechanism type for case study 3 in UB3LYP/6-31G(d,p). The R1 and R2 positions are substituted with CF_3, CN, and NO_2 electron-withdrawing groups. The energy value is in kcal/mol.

System	$\Delta E^{\neq}$	ΔE^{o}	Mechanism
H-H	24.61	-50.46	Synchronous one-step
CF_3 - CF_3	22.82	-47.68	Asynchronous one-step
CN-CN	13.30	-49.22	Asynchronous one-step
NO_2-NO_2 (TS1)	16.4	-55.7	Stepwise

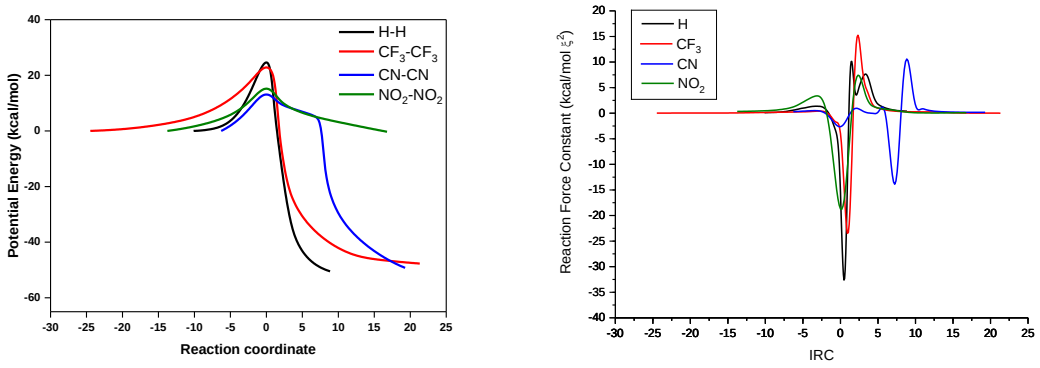


Figure S6: Potential energy (left) and reaction force constant (right) profiles for case study 2 in UB3LYP/6-31G(d,p). The R1 and R2 positions are substituted with CF_3, CN, and NO_2 electron-withdrawing groups.

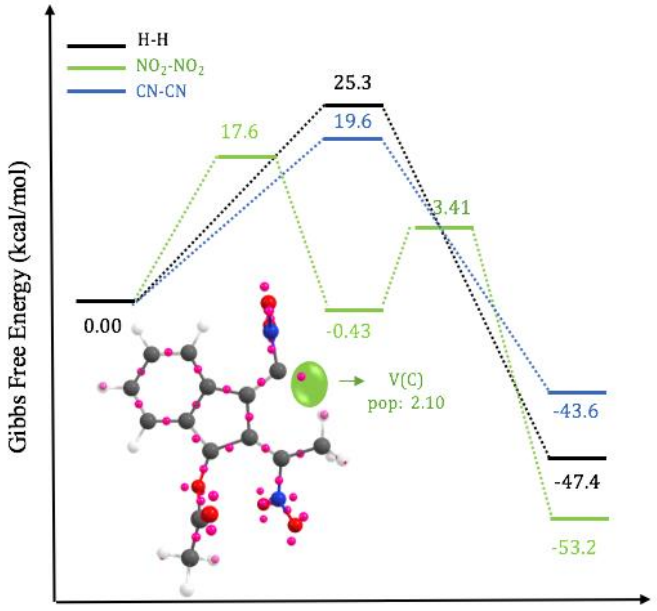


Figure S7: Gibbs free energy Diagram for case study 3 in UB3LYP/6-31G(d,p). The R1 and R2 positions are substituted with CF_3, CN, and NO_2 electron-withdrawing groups. Basin attractors of the Electron Localization Function (ELF) for the intermediate (R1: NO_2, R2: NO_2) and the population of the carbon basin are highlighted in green.

Table S5. Natural atomic charges of the atoms that form the new bonds C2-C6 and C7-H.

	-H	-CN	$-NO_2$
C2	-0.043	-0.022	-0.059
C6	-0.047	0.014	-0.045
C7	-0.284	-0.068	0.163
H	0.251	0.268	0.272

5. Summary of quasiclassical molecular dynamics for system R1 and R2 positions CN substituted

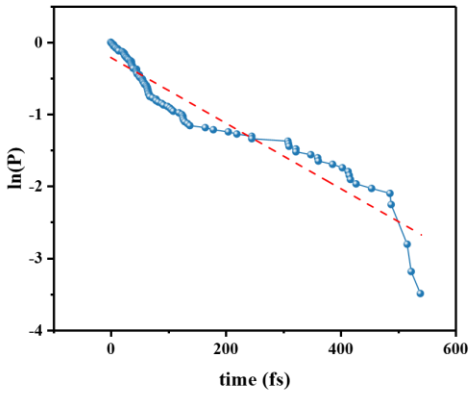


Figure S8: ln(P) vs. Time plot. The linear fitted function is: ln(P) = -0.0046t - 0.213; R^2=0.91.

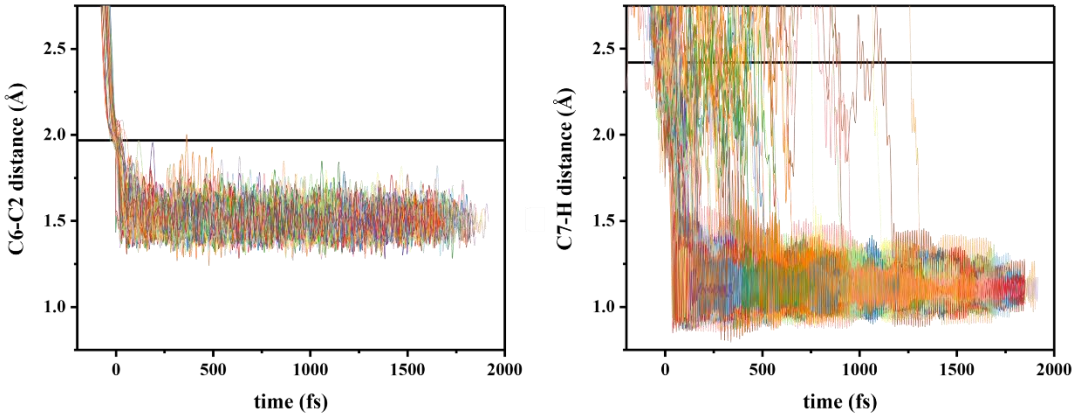


Figure S9: Time evolution of two bond distances of interest.

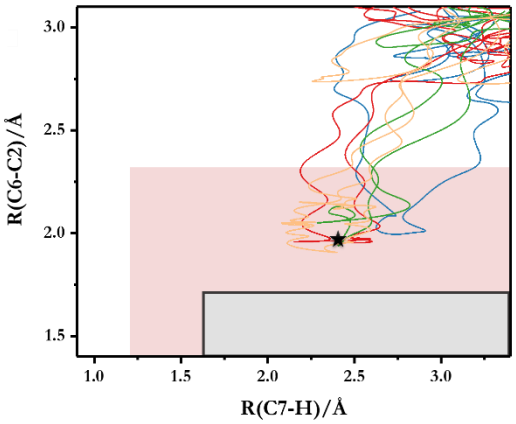


Figure S10: Some of the trajectories that showed recrossing. None of them visited the intermediate region (shown in the grey square).

Tabla S6. Trajectories, type of trajectory (**p**: productive, **uf**: unfinished, **r**: recrossing and **np**: non-productive), the internuclear distance of two bonds of interest at the sampled structure ($\mathbf{d_{C\text{-}C}}$ and $\mathbf{d_{C\text{-}H}}$), time of entrance in the intermediate region ($\mathbf{t_{start\text{-}RI}}$), time of departure from the intermediate region ($\mathbf{t_{end\text{-}RI}}$) and intermediate lifetime ($\mathbf{t_{life\text{-}RI}}$).

Trajectory	Type	$d_{C\text{-}C}$	$d_{C\text{-}H}$	$t_{start\text{-}RI}$	$t_{end\text{-}RI}$	$t_{life\text{-}RI}$
1	p	2.067	2.779	45	463	418
2	p	1.926	2.524	29	109	79
3	p	2.083	2.540	2	53	52
4	p	2.011	2.736	15	179	165
5	p	2.067	2.379	37	92	55
6	p	1.987	2.519	50	373	323
7	p	1.958	2.703	17	421	404
8	p	2.007	2.274	28	36	8
9	p	1.933	2.923	23	53	31
10	p	2.033	2.505	21	41	20
11	p	2.050	2.406	31	169	138
12	p	1.914	2.331	38	259	220
13	p	1.942	2.544	22	141	119
14	p	1.974	2.232	23	61	39
15	p	1.948	3.299	13	91	79
16	p	1.914	2.597	12	322	310
17	p	2.010	2.268	46	105	59
18	p	2.025	2.704	23	96	73
19	p	2.005	2.168	33	35	2
20	p	2.000	2.577	19	102	83
21	p	1.980	2.572	20	329	309
22	p	2.003	2.528	23	150	127
23	p	1.996	2.549	34	558	524
24	p	2.004	2.248	19	43	24

25	p	2.018	2.571	17	503	487
26	p	2.095	2.539	57	93	36
27	p	2.074	2.161	27	273	246
28	p	1.999	2.510	43	94	50
29	p	2.075	2.164	28	73	45
30	p	1.992	2.401	51	59	9
31	p	2.001	2.423	58	82	24
32	p	2.088	2.247	37	73	36
33	p	1.995	2.308	28	137	109
34	p	1.991	2.286	26	90	64
35	p	2.006	2.298	21	67	46
36	p	1.965	2.282	22	24	1
37	p	2.001	2.367	32	96	65
38	p	2.071	2.689	22	121	99
39	p	1.965	3.196	12	335	323
40	p	1.965	2.024	48	60	12
41	p	1.943	2.324	32	487	455
42	p	2.065	2.144	30	210	179
43	p	1.990	2.404	17	54	37
44	p	2.075	2.560	45	357	311
45	p	1.957	2.318	18	25	7
46	p	2.025	2.333	24	38	14
47	p	1.915	2.658	16	222	205
48	p	2.013	2.810	46	59	12
49	p	1.983	2.681	24	86	62
50	p	1.960	1.695	38	94	56
51	p	2.090	2.765	33	160	126
52	p	1.969	2.353	35	62	27
53	p	1.919	2.149	38	104	66
54	p	2.028	2.437	34	71	37
55	p	2.026	2.999	72	94	21
56	p	1.933	2.356	29	75	46
57	p	2.008	2.206	24	69	45
58	p	2.074	2.161	27	273	246
59	p	1.999	2.510	43	94	50
60	p	2.075	2.164	28	73	45
61	p	1.974	2.496	40	528	489
62	p	1.990	2.464	26	48	23
63	p	2.016	2.166	23	48	25
64	p	2.093	2.590	24	69	45
65	p	2.032	2.556	33	98	65
66	p	1.905	2.480	9	425	416
67	p	1.990	2.711	24	63	39
68	p	1.994	2.483	23	59	36
69	p	1.960	3.032	17	557	540
70	p	1.940	2.552	34	39	5
71	p	1.930	2.801	15	377	362
72	p	1.988	2.269	23	157	134
73	p	1.873	2.711	9	396	387

74	p	2.011	2.522	27	84	56
75	p	1.971	2.102	37	72	34
76	p	1.942	1.905	22	25	3
77	p	1.967	2.748	29	443	414
78	p	2.029	2.310	43	80	38
79	p	2.057	2.032	17	82	66
80	p	2.084	2.557	26	94	68
81	p	2.080	2.310	29	79	50
82	p	2.048	2.221	39	75	36
83	p	2.056	2.645	24	81	57
84	p	2.001	2.232	21	127	106
85	p	2.084	2.378	35	59	24
86	p	2.018	2.273	35	64	29
87	p	1.990	2.307	24	87	64
88	p	2.005	1.967	21	89	68
89	p	1.981	2.423	32	37	5
90	p	2.054	2.753	21	113	92
91	p	1.935	2.406	12	360	349
92	p	1.997	2.189	39	102	63
93	p	1.956	2.449	55	81	27
94	p	2.043	1.884	21	35	14
95	p	2.033	2.047	17	141	124
96	p	2.060	2.779	35	165	129
97	p	1.975	2.183	27	388	361
98	p	1.952	2.501	29	88	59
99	p	1.967	2.289	28	153	126
100	p	1.995	2.541	22	53	30
101	p	1.994	2.358	47	475	428
102	p	2.024	2.179	27	116	89
103	p	2.043	1.745	32	136	103
104	p	2.009	2.391	20	537	517
105	p	2.034	2.522	30	34	5
106	uf	1.951	2.485	18	560	542
107	uf	1.905	2.794	10	1100	1090
108	uf	1.908	2.109	18	1163	1145
109	uf	2.008	2.166	57	1305	1248
110	uf	1.992	2.573	25	568	543
111	uf	1.917	2.645	15	904	889
112	uf	1.913	2.332	56	762	706
113	uf	1.921	1.992	26	635	609
114	uf	2.020	2.485	19	891	872
115	uf	2.070	1.783	21	949	929
116	uf	1.912	2.327	31	1911	1880
117	uf	1.979	2.563	18	1994	1976
118	uf	1.943	2.571	12	1645	1633
119	uf	1.855	3.032	45	1697	1652
120	uf	2.066	2.773	15	1892	1877
121	uf	1.940	2.999	30	2099	2069
122	uf	2.000	2.288	26	2046	2020

123	uf	1.942	2.673	13	1928	1916
124	uf	2.007	2.592	18	1870	1852
125	uf	1.928	2.266	15	1968	1953
126	uf	1.972	2.301	14	1563	1549
127	uf	1.895	2.453	12	1564	1552
128	uf	1.973	2.287	52	1495	1443
129	uf	1.905	2.619	9	1833	1824
130	uf	1.886	2.580	15	1788	1774
131	uf	1.959	2.492	19	2002	1983
132	uf	1.953	2.368	12	1878	1867
133	uf	1.946	2.599	15	2069	2054
134	uf	1.933	2.570	11	2074	2062
135	uf	1.899	2.529	12	1649	1636
136	uf	1.878	2.329	7	1968	1961
137	uf	1.855	2.421	9	1835	1826
138	uf	2.035	2.640	22	2002	1980
139	uf	1.945	2.293	19	1666	1647
140	uf	1.917	2.419	23	1655	1632
141	uf	1.993	2.492	18	1871	1853
142	uf	1.953	2.586	15	2015	2000
143	uf	1.860	2.767	9	1546	1536
144	uf	2.057	2.348	13	1337	1324
145	uf	1.907	2.338	15	1717	1702
146	uf	1.873	2.751	26	1399	1373
147	uf	1.966	2.419	29	1688	1658
148	uf	1.996	2.733	27	1873	1846
149	uf	1.957	2.726	18	1793	1775
150	uf	1.914	2.576	15	1935	1920
151	uf	2.012	2.780	17	1755	1738
152	uf	1.884	2.864	10	2019	2009
153	uf	2.086	2.549	39	1934	1895
154	uf	1.906	2.615	9	1721	1712
155	uf	1.932	2.842	9	1668	1659
156	uf	1.875	2.264	12	1946	1934
157	uf	1.902	2.636	11	1861	1850
158	uf	1.996	2.699	18	1812	1794
159	uf	1.967	2.874	9	1703	1694
160	uf	1.969	2.479	18	1522	1504
161	uf	1.893	2.783	14	1561	1547
162	uf	1.935	2.323	11	1918	1907
163	uf	1.789	2.558	6	1884	1878
164	uf	1.954	2.156	21	1997	1976
165	uf	2.001	2.576	15	1767	1752
166	uf	1.989	2.181	16	1761	1744
167	uf	1.885	2.664	11	1624	1614
168	uf	1.953	2.560	12	1745	1733
169	uf	1.827	2.309	7	1765	1758
170	uf	2.043	2.319	19	1770	1751
171	uf	1.860	2.939	13	1918	1905

172	uf	2.003	2.398	28	1759	1730
173	uf	2.049	2.821	27	1842	1815
174	uf	1.940	2.258	23	1991	1968
175	uf	1.918	2.198	21	1791	1770
176	uf	1.951	2.890	12	1325	1313
177	uf	1.897	2.197	16	1690	1674
178	uf	2.029	2.944	32	1658	1626
179	uf	1.913	2.380	20	1378	1358
180	uf	1.935	2.997	14	1915	1900
181	uf	1.986	2.743	15	1609	1594
182	uf	1.880	2.451	10	2010	2000
183	uf	1.831	2.575	10	1926	1915
184	uf	1.905	2.798	9	1741	1732
185	uf	1.976	2.492	23	1953	1930
186	uf	1.878	2.296	15	1948	1934
187	uf	1.939	2.625	27	1775	1748
188	uf	1.909	2.067	40	1983	1944
189	uf	1.913	2.380	12	1974	1962
190	uf	1.994	2.384	13	1982	1970
191	uf	1.932	2.842	9	1668	1659
192	uf	1.875	2.264	12	1946	1934
193	uf	1.992	2.401	46	2199	2153
194	uf	1.902	2.636	11	2145	2134
195	uf	1.996	2.699	18	2335	2317
196	uf	1.967	2.874	9	1798	1789
197	uf	1.963	2.513	16	1382	1366
198	uf	2.011	2.127	15	2665	2650
199	uf	1.989	2.634	33	1960	1928
200	uf	1.996	2.612	33	1441	1407
201	uf	1.916	2.577	16	1962	1947
202	uf	1.907	2.405	20	1995	1974
203	uf	1.941	2.802	21	1885	1864
204	uf	2.073	2.288	23	1562	1539
205	uf	1.916	2.537	27	1945	1918
206	uf	1.968	2.325	31	2040	2009
207	uf	1.946	1.999	21	1688	1668
208	uf	1.958	2.452	15	1890	1875
209	uf	1.970	2.291	25	2727	2702
210	uf	1.856	2.638	7	2142	2135
211	uf	1.907	2.733	15	1884	1869
212	uf	1.998	2.490	48	1341	1293
213	uf	1.941	2.437	23	1627	1604
214	uf	1.997	2.468	14	1631	1616
215	uf	1.910	2.387	14	1628	1613
216	uf	1.917	2.516	17	1976	1959
217	uf	1.931	2.182	12	1657	1645
218	uf	1.847	2.602	7	1526	1519
219	uf	1.986	2.772	15	1692	1677
220	uf	1.949	2.733	42	1901	1858

221	uf	1.819	2.572	6	1506	1500
222	uf	1.939	2.546	14	1641	1627
223	uf	1.910	2.557	17	1618	1601
224	uf	1.939	2.593	14	1620	1605
225	uf	1.982	2.580	13	1737	1724
226	uf	1.904	2.601	12	2043	2031
227	uf	1.928	2.416	10	2013	2003
228	uf	1.972	2.484	14	2040	2026
229	r	1.806	2.324			
230	r	1.864	2.276			
231	r	1.955	2.557			
232	r	2.010	2.419			
233	r	2.096	2.412			
234	r	1.817	3.242			
235	r	1.967	2.442			
236	r	2.018	2.583			
237	r	2.087	3.263			
238	r	2.009	2.393			
239	r	1.975	2.114			
240	r	2.044	2.108			
241	r	2.043	2.661			
242	r	2.091	2.242			
243	r	1.976	2.544			
244	r	2.081	3.083			
245	r	1.975	2.114			
246	r	1.844	2.750			
247	r	2.064	3.001			
248	r	2.096	2.724			
249	r	2.006	2.877			
250	np	1.983	2.868			
251	np	1.906	2.754			
252	np	1.927	2.612			
253	np	1.941	2.660			
254	np	2.028	2.298			
255	np	2.050	1.983			
256	np	1.993	2.429			

5. Cartesian Coordinates of the systems studied in this paper

Cartesian coordinates using B3LYP combined with the 6-311+G(d,p) basis set. Optimized geometries are given below in standard XYZ format. Each case shows the total number of atoms before the cartesian coordinate.

Isolated reactants

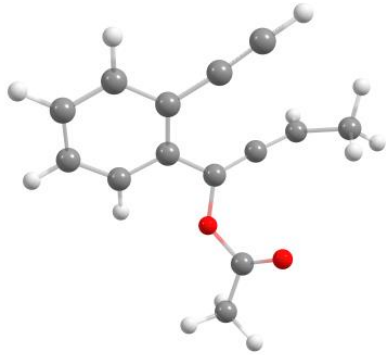


Figure S11: Enyne unsubstituted (R1: H and R2: H) computed structure.

#p opt freq Ub3lyp/6-311+G(d,p) nosymm int=(grid=ultrafine)

SCF Done =	-691.237912098
Zero-point correction =	0.215489 (Hartree/Particle)
Thermal correction to Energy =	0.232625
Thermal correction to Enthalpy =	0.232625
Thermal correction to Gibbs Free Energy =	0.169523
Sum of electronic and zero-point Energies =	-691.022423
Sum of electronic and thermal Energies =	-691.006231
Sum of electronic and thermal Enthalpies =	-691.005287
Sum of electronic and thermal Free Energies =	-691.068389

28

C	-1.186337000	-2.944890000	-1.874542000
C	0.193634000	-2.749227000	-1.897562000
C	0.741336000	-1.608231000	-1.324068000
C	-0.063721000	-0.632965000	-0.717746000
C	-1.464907000	-0.837593000	-0.684320000
C	-2.001905000	-1.997119000	-1.272438000
C	0.588534000	0.566974000	-0.155608000
O	1.929963000	0.365436000	0.274516000
C	-2.374149000	0.060055000	-0.048212000
C	-3.214301000	0.745670000	0.477221000
H	-3.939834000	1.361389000	0.949171000
C	0.121302000	1.788269000	-0.120768000
C	-0.298156000	3.021264000	-0.093266000

C	-1.080080000	3.649458000	1.029959000
C	2.118765000	-0.068835000	1.560696000
H	-3.074367000	-2.143472000	-1.234006000
H	-1.624016000	-3.832032000	-2.317273000
H	1.812261000	-1.453448000	-1.351592000
H	0.842685000	-3.481260000	-2.364497000
H	-0.546932000	4.522000000	1.421179000
H	-2.051060000	4.000801000	0.665413000
H	-1.243850000	2.943215000	1.843241000
O	1.225215000	-0.256438000	2.339359000
C	3.588262000	-0.264671000	1.828962000
H	4.139627000	0.646888000	1.590091000
H	3.732298000	-0.530254000	2.874107000
H	3.977211000	-1.061138000	1.189682000
H	-0.079683000	3.656227000	-0.952726000

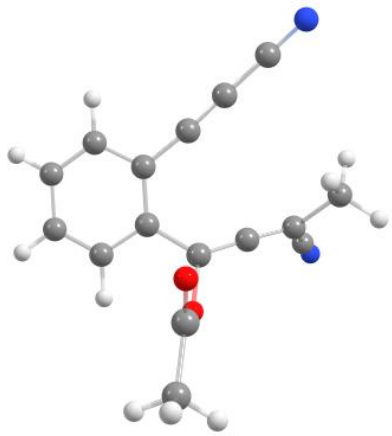


Figure S12: Enyne substituted (R1: CN and R2: CN) computed structure.

#p opt freq Ub3lyp/6-311+G(d,p) nosymm int=(grid=ultrafine)

SCF Done =	-875.772233193
Zero-point correction =	0.214154 (Hartree/Particle)
Thermal correction to Energy =	0.233811
Thermal correction to Enthalpy =	0.234755
Thermal correction to Gibbs Free Energy =	0.162502
Sum of electronic and zero-point Energies =	-875.558079
Sum of electronic and thermal Energies =	-875.538423
Sum of electronic and thermal Enthalpies =	-875.537478
Sum of electronic and thermal Free Energies =	-875.609731

30

C	-0.601421000	-3.350250000	-2.078499000
C	0.771995000	-3.114298000	-2.034251000

C	1.267840000	-2.001993000	-1.363690000
C	0.411200000	-1.097140000	-0.725938000
C	-0.982945000	-1.343409000	-0.760358000
C	-1.469520000	-2.472776000	-1.445802000
C	1.003020000	0.084371000	-0.064061000
O	2.299309000	-0.101796000	0.463052000
C	-1.929891000	-0.519293000	-0.098459000
C	-2.809951000	0.109746000	0.447279000
C	0.505588000	1.292254000	-0.027994000
C	0.066709000	2.528813000	-0.000327000
C	-0.811216000	3.100673000	1.093985000
C	2.383838000	-0.685420000	1.711268000
H	-2.537409000	-2.651548000	-1.460014000
H	-0.993745000	-4.215599000	-2.599015000
H	2.333834000	-1.815476000	-1.341646000
H	1.458080000	-3.793448000	-2.526686000
H	-0.322306000	3.967253000	1.546755000
H	-1.765810000	3.435389000	0.680238000
H	-0.996230000	2.353033000	1.863235000
O	1.420528000	-0.999659000	2.350552000
C	3.824538000	-0.842882000	2.110044000
H	4.337042000	-1.498799000	1.402402000
H	4.327529000	0.125949000	2.081826000
H	3.876867000	-1.265037000	3.111143000
C	-3.785293000	0.834781000	1.064976000
N	-4.612161000	1.457028000	1.590301000
C	0.434042000	3.413568000	-1.072067000
N	0.709182000	4.153593000	-1.915755000

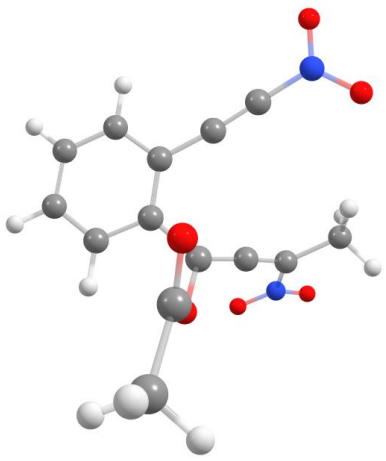


Figure S13: Enyne substituted (R1: NO_2 and R2: NO_2) computed structure.

#p opt freq Ub3lyp/6-311+G(d,p) nosymm int=(grid=ultrafine)

SCF Done = -1100.34035602
Zero-point correction = 0.221168 (Hartree/Particle)

Thermal correction to Energy = 0.242619
Thermal correction to Enthalpy = 0.243563
Thermal correction to Gibbs Free Energy = 0.165980
Sum of electronic and zero-point Energies = -1100.119188
Sum of electronic and thermal Energies = -1100.097737
Sum of electronic and thermal Enthalpies = -1100.096793
Sum of electronic and thermal Free Energies = -1100.174376

32

C	-0.347619000	-3.438325000	-2.276377000
C	1.018246000	-3.155481000	-2.265218000
C	1.508787000	-2.098394000	-1.505820000
C	0.649053000	-1.299221000	-0.746543000
C	-0.734800000	-1.593534000	-0.744659000
C	-1.216147000	-2.664770000	-1.520789000
C	1.228877000	-0.163361000	0.003862000
O	2.450580000	-0.402664000	0.652770000
C	-1.664130000	-0.881226000	0.056440000
C	-2.515603000	-0.350181000	0.724381000
C	0.780807000	1.063694000	-0.018779000
C	0.397184000	2.307511000	-0.092772000
C	-0.553470000	3.042282000	0.796056000
C	2.414894000	-1.207285000	1.776714000
H	-2.276890000	-2.881908000	-1.506219000
H	-0.732077000	-4.260518000	-2.867762000
H	2.567698000	-1.871691000	-1.511566000
H	1.702574000	-3.753946000	-2.855183000
H	-0.040444000	3.862299000	1.303986000
H	-1.365618000	3.479722000	0.210966000
H	-0.972887000	2.362309000	1.535586000
O	1.397439000	-1.658889000	2.218719000
C	3.802863000	-1.394413000	2.319957000
H	4.439809000	-1.861331000	1.565299000
H	4.240296000	-0.423304000	2.561709000
H	3.759618000	-2.017915000	3.210136000
N	1.006885000	3.124499000	-1.209898000
O	1.737456000	2.562483000	-2.009499000
O	0.713637000	4.310879000	-1.229928000
N	-3.479492000	0.266729000	1.506807000
O	-3.099807000	1.154860000	2.270388000
O	-4.638774000	-0.117473000	1.377615000

Transition states (TS)

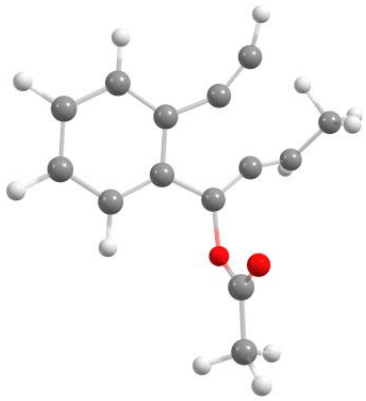


Figure S14: Transition state structure of the unsubstituted system (R1: H and R2: H).

#p opt=(calcfc,ts,tight,noeigentest) freq ub3lyp/6-311+G(d,p) nosymm int=(grid=ultrafine)

SCF Done =	-691.193959684
Zero-point correction =	0.212352 (Hartree/Particle)
Thermal correction to Energy =	0.227828
Thermal correction to Enthalpy =	0.227828
Thermal correction to Gibbs Free Energy =	0.169353
Sum of electronic and zero-point Energies =	-690.981608
Sum of electronic and thermal Energies =	-690.967076
Sum of electronic and thermal Enthalpies =	-690.966132
Sum of electronic and thermal Free Energies =	-691.024607

28

C	-0.507417000	-4.078537000	-1.540585000
C	0.881578000	-4.172287000	-1.426480000
C	1.622215000	-3.114044000	-0.901946000
C	0.960705000	-1.958335000	-0.491020000
C	-0.440298000	-1.861271000	-0.597833000
C	-1.172492000	-2.923409000	-1.131139000
C	1.552749000	-0.747629000	0.062007000
O	2.912434000	-0.734289000	0.393624000
C	-1.024149000	-0.630785000	-0.101531000
C	-2.030581000	0.038377000	0.220029000
H	-3.078243000	0.127096000	0.418041000
C	0.758375000	0.303125000	0.223613000
C	0.556108000	1.631002000	0.386006000
C	-0.509704000	2.091066000	1.234748000
C	3.276755000	-1.125646000	1.660601000
H	-2.250271000	-2.848122000	-1.212559000
H	-1.073791000	-4.909870000	-1.944264000
H	2.701009000	-3.179974000	-0.826120000
H	1.388609000	-5.074088000	-1.750509000
H	-0.717613000	3.158784000	1.206266000
H	-1.433250000	1.463354000	0.754103000
H	-0.518186000	1.693068000	2.249237000

O	2.492933000	-1.466796000	2.500927000
C	4.771950000	-1.040172000	1.813624000
H	5.090949000	-0.000403000	1.708300000
H	5.057327000	-1.416288000	2.793680000
H	5.267422000	-1.615265000	1.028828000
H	0.925250000	2.294874000	-0.395658000

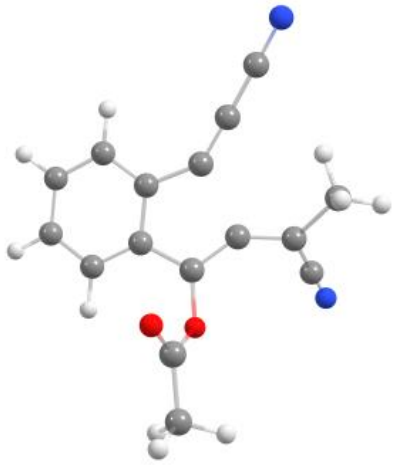


Figure S15: Transition state structure of the substituted system with R1: CN and R2: CN.

#p opt=(calcfc,ts,tight,noeigentest) freq ub3lyp/6-311+G(d,p) nosymm int=(grid=ultrafine)

SCF Done = -875.738365474
Zero-point correction = 0.212419 (Hartree/Particle)
Thermal correction to Energy = 0.231155
Thermal correction to Enthalpy = 0.232099
Thermal correction to Gibbs Free Energy = 0.163161
Sum of electronic and zero-point Energies = -875.525946
Sum of electronic and thermal Energies = -875.507211
Sum of electronic and thermal Enthalpies = -875.506266
Sum of electronic and thermal Free Energies = -875.575205

30

C	-0.386689000	-4.027791000	-1.740069000
C	1.009377000	-4.055083000	-1.648285000
C	1.701263000	-3.007276000	-1.047759000
C	0.979153000	-1.928927000	-0.537220000
C	-0.425662000	-1.901043000	-0.625349000
C	-1.112091000	-2.947831000	-1.241545000
C	1.481443000	-0.730950000	0.098647000
O	2.791597000	-0.619582000	0.512957000
C	-1.053247000	-0.728080000	-0.039394000
C	-2.187516000	-0.254587000	0.208000000
C	0.583977000	0.251731000	0.312691000
C	0.510376000	1.595100000	0.481894000
C	-0.549968000	2.234354000	1.317125000

C	3.205227000	-1.327588000	1.636666000
H	-2.192676000	-2.924700000	-1.308901000
H	-0.911574000	-4.859407000	-2.195188000
H	2.783183000	-3.017356000	-0.995887000
H	1.556757000	-4.899661000	-2.050002000
H	-0.490218000	3.321068000	1.297395000
H	-1.530247000	1.921935000	0.919237000
H	-0.514627000	1.880446000	2.349803000
O	2.455740000	-1.984772000	2.296425000
C	4.671674000	-1.103639000	1.864676000
H	5.239901000	-1.399909000	0.980403000
H	4.858603000	-0.040024000	2.029525000
H	4.994027000	-1.677838000	2.730328000
C	-3.412787000	0.222561000	0.509554000
N	-4.480104000	0.622517000	0.763908000
C	1.374349000	2.428056000	-0.284934000
N	2.081811000	3.126298000	-0.879817000

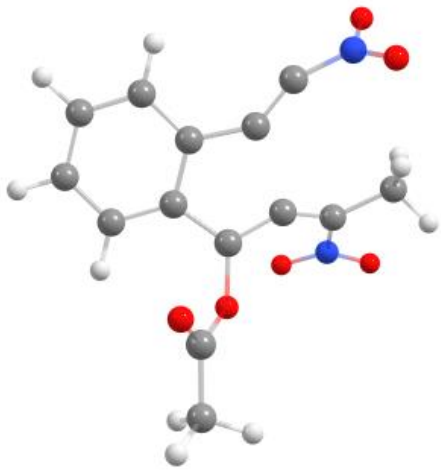


Figure S16: First transition state structure of the substituted system with R1: NO_2 and R2: NO_2.

#p opt=(calcfc,ts,tight,noeigentest) freq ub3lyp/6-311+G(d,p) nosymm int=(grid=ultrafine)

SCF Done =	-1100.30960370
Zero-point correction =	0.219529 (Hartree/Particle)
Thermal correction to Energy =	0.240044
Thermal correction to Enthalpy =	0.240988
Thermal correction to Gibbs Free Energy =	0.167268
Sum of electronic and zero-point Energies =	-1100.090075
Sum of electronic and thermal Energies =	-1100.069560
Sum of electronic and thermal Enthalpies =	-1100.068616
Sum of electronic and thermal Free Energies =	-1100.142335

32

C	-0.265455000	-4.034336000	-1.808395000

C	1.135669000	-3.988251000	-1.713656000
C	1.761345000	-2.950177000	-1.044081000
C	0.974869000	-1.946537000	-0.463293000
C	-0.433692000	-1.996661000	-0.548815000
C	-1.053738000	-3.038498000	-1.248886000
C	1.418471000	-0.755899000	0.205219000
O	2.684730000	-0.585550000	0.684512000
C	-1.143678000	-0.930266000	0.116190000
C	-2.309900000	-0.586806000	0.426037000
C	0.471360000	0.202095000	0.403614000
C	0.337533000	1.526342000	0.395986000
C	-0.699666000	2.354909000	1.064802000
C	3.211802000	-1.477238000	1.629196000
H	-2.133232000	-3.071660000	-1.321345000
H	-0.738729000	-4.863596000	-2.321139000
H	2.841656000	-2.897814000	-0.992776000
H	1.729522000	-4.768984000	-2.173623000
H	-0.222399000	3.181973000	1.594169000
H	-1.380785000	2.801444000	0.332980000
H	-1.267490000	1.757528000	1.774236000
O	2.566374000	-2.355012000	2.114241000
C	4.637092000	-1.110010000	1.913775000
H	5.211987000	-1.079827000	0.985984000
H	4.674318000	-0.109512000	2.351407000
H	5.064509000	-1.833079000	2.604718000
N	1.336019000	2.307741000	-0.432933000
O	2.052062000	1.703192000	-1.214807000
O	1.355580000	3.517386000	-0.249034000
N	-3.256659000	0.285514000	0.890175000
O	-3.314891000	0.470787000	2.114087000
O	-4.007727000	0.807499000	0.057689000

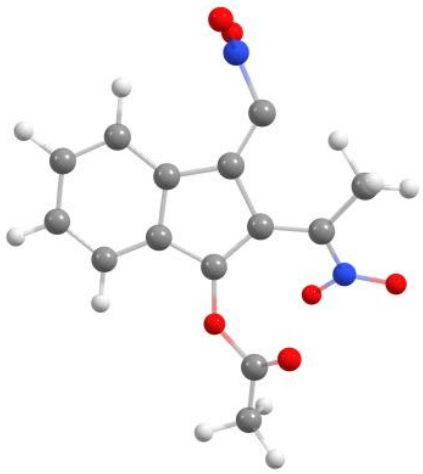


Figure S17: Second transition state structure of the substituted system with R1: NO_2 and R2: NO_2.

#p opt=(calcfc,ts,tight,noeigentest) freq ub3lyp/6-311+G(d,p) nosymm int=(grid=ultrafine)

SCF Done = -1100.33867421
Zero-point correction = 0.219313 (Hartree/Particle)
Thermal correction to Energy = 0.238367
Thermal correction to Enthalpy = 0.239312
Thermal correction to Gibbs Free Energy = 0.170416
Sum of electronic and zero-point Energies = -1100.119361
Sum of electronic and thermal Energies = -1100.100307
Sum of electronic and thermal Enthalpies = -1100.099363
Sum of electronic and thermal Free Energies = -1100.168258

32

C	-1.191575000	-3.534991000	-1.709207000
C	0.198546000	-3.756861000	-1.608972000
C	1.025799000	-2.796784000	-1.059570000
C	0.437773000	-1.601645000	-0.607436000
C	-0.961029000	-1.377761000	-0.703195000
C	-1.780288000	-2.353766000	-1.273704000
C	1.038530000	-0.468658000	0.008751000
O	2.351961000	-0.522266000	0.282674000
C	-1.268851000	-0.060842000	-0.148168000
C	-2.403916000	0.638523000	-0.173632000
C	0.061231000	0.525640000	0.273803000
C	0.140623000	1.835554000	0.709532000
C	-1.003127000	2.550151000	1.215778000
C	2.951962000	0.077984000	1.406477000
H	-2.849584000	-2.213870000	-1.358549000
H	-1.818374000	-4.311736000	-2.132158000
H	2.096896000	-2.941667000	-0.994359000
H	0.615013000	-4.688900000	-1.971722000
H	-0.884538000	3.628602000	1.241896000
H	-1.877334000	2.167357000	0.533449000
H	-1.351880000	2.161137000	2.176131000
O	2.312875000	0.503380000	2.317637000
C	4.437552000	0.044473000	1.247633000
H	4.714446000	0.730373000	0.442492000
H	4.906990000	0.358137000	2.177220000
H	4.771287000	-0.955402000	0.965534000
N	1.380075000	2.629885000	0.474764000
O	2.210007000	2.188346000	-0.314726000
O	1.490577000	3.676659000	1.093129000
N	-3.645840000	0.156397000	-0.616025000
O	-4.352035000	-0.448702000	0.199127000
O	-3.987431000	0.434801000	-1.769924000

Intermediate (Int)

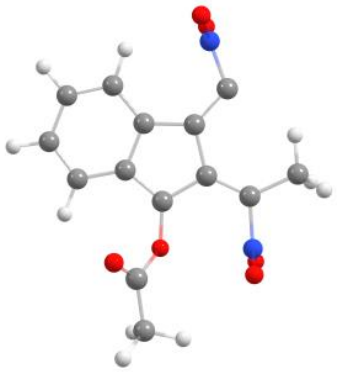


Figure S18: Intermediate compute the structure of the substituted system with R1: NO_2 and R2: NO_2.

opt freq Ub3lyp/6-311+G(d,p) nosymm int=(grid=ultrafine)

SCF Done =	-1100.34599062
Zero-point correction =	0.222467 (Hartree/Particle)
Thermal correction to Energy =	0.239648
Thermal correction to Enthalpy =	0.240592
Thermal correction to Gibbs Free Energy =	0.176392
Sum of electronic and zero-point Energies =	-1100.123524
Sum of electronic and thermal Energies =	-1100.105399
Sum of electronic and thermal Enthalpies =	-1100.099363
Sum of electronic and thermal Free Energies =	-1100.169598

32

C	-1.097790000	-3.537917000	-1.042719000
C	0.292213000	-3.707481000	-0.783645000
C	1.060234000	-2.641982000	-0.424999000
C	0.428851000	-1.374467000	-0.326729000
C	-0.968895000	-1.197708000	-0.585954000
C	-1.731432000	-2.323723000	-0.951250000
C	0.961718000	-0.133332000	-0.023619000
O	2.241935000	0.146923000	0.245171000
C	-1.331182000	0.189380000	-0.426828000
C	-2.538302000	0.812153000	-0.493228000
C	-0.063266000	0.885468000	-0.089062000
C	0.144433000	2.202033000	0.110787000
C	-0.810876000	3.331727000	0.048885000
C	2.843142000	-0.339779000	1.422213000
H	-2.787735000	-2.243404000	-1.165884000
H	-1.677904000	-4.408988000	-1.326975000
H	2.118063000	-2.747217000	-0.219674000
H	0.729547000	-4.694004000	-0.874780000
H	-0.536182000	3.980496000	-0.789597000
H	-1.821987000	2.950882000	-0.090713000
H	-0.740561000	3.920776000	0.968246000
O	2.261906000	-1.056249000	2.167103000

C	4.216521000	0.227474000	1.532670000
H	4.136676000	1.313915000	1.622473000
H	4.707229000	-0.187834000	2.409792000
H	4.786790000	0.007276000	0.628364000
N	1.521935000	2.669946000	0.416743000
O	2.176075000	3.076871000	-0.513478000
O	1.853718000	2.664769000	1.583435000
N	-3.653492000	0.000469000	-0.756609000
O	-4.258429000	-0.464873000	0.202675000
O	-4.002354000	-0.127949000	-1.926254000

Isolated Products

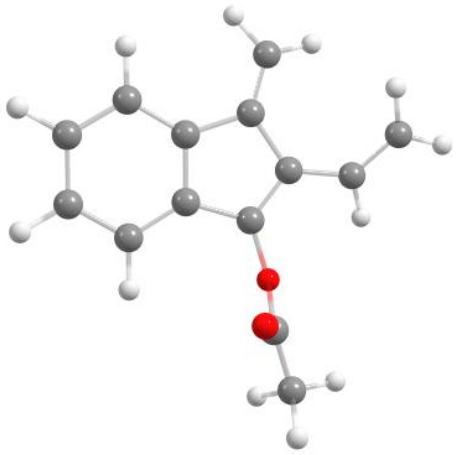


Figure S19: Allene unsubstituted (R1: H and R2: H) computed structure.

opt freq Ub3lyp/6-311+G(d,p) nosymm int=(grid=ultrafine)

SCF Done =	-691.314153636
Zero-point correction =	0.219121 (Hartree/Particle)
Thermal correction to Energy =	0.233737
Thermal correction to Enthalpy =	0.234681
Thermal correction to Gibbs Free Energy =	0.176248
Sum of electronic and zero-point Energies =	-691.095033
Sum of electronic and thermal Energies =	-691.080416
Sum of electronic and thermal Enthalpies =	-691.079472

Sum of electronic and thermal Free Energies = -691.137905

28

C	-1.528037000	-2.936965000	-1.677062000
C	-0.156638000	-3.101913000	-1.470750000
C	0.614016000	-2.071706000	-0.926625000
C	-0.019849000	-0.879226000	-0.595014000
C	-1.403300000	-0.705052000	-0.807848000
C	-2.161111000	-1.732928000	-1.349264000
C	0.472815000	0.368272000	-0.025795000
O	1.802782000	0.620387000	0.249024000
C	-1.764994000	0.673941000	-0.396542000
C	-2.962918000	1.247993000	-0.574734000
H	-3.786074000	0.690915000	-1.007118000
C	-0.519844000	1.290579000	0.126927000
C	-0.313279000	2.615046000	0.691096000
C	-1.219219000	3.413899000	1.270940000
C	2.404312000	-0.026156000	1.308440000
H	-3.226296000	-1.616978000	-1.516753000
H	-2.108902000	-3.751285000	-2.094741000
H	1.676532000	-2.207447000	-0.763774000
H	0.314508000	-4.042630000	-1.732017000
H	-0.926186000	4.380027000	1.664180000
H	-3.152687000	2.282219000	-0.324470000
H	-2.254775000	3.129820000	1.405813000
O	1.821146000	-0.777841000	2.035991000
C	3.853591000	0.367103000	1.392211000
H	3.936541000	1.446218000	1.540656000
H	4.322936000	-0.158487000	2.220830000
H	4.362481000	0.126056000	0.456377000
H	0.717627000	2.958545000	0.652951000

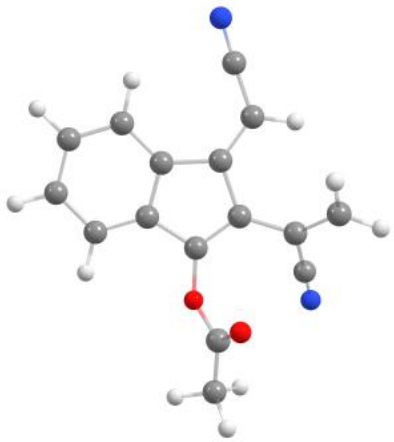


Figure S20: Allene substituted (R1: CN and R2: CN) computed structure.

opt freq Ub3lyp/6-311+G(d,p) nosymm int=(grid=ultrafine)

SCF Done =	875.843777374
Zero-point correction =	0.216990 (Hartree/Particle)
Thermal correction to Energy =	0.234866
Thermal correction to Enthalpy =	0.235810
Thermal correction to Gibbs Free Energy =	0.170113
Sum of electronic and zero-point Energies =	-875.626788
Sum of electronic and thermal Energies =	-875.608912
Sum of electronic and thermal Enthalpies =	-875.607968
Sum of electronic and thermal Free Energies =	-875.673664

30

C	-1.504584000	-3.279325000	-1.626368000
C	-0.136896000	-3.536264000	-1.548236000
C	0.742582000	-2.576672000	-1.033497000
C	0.210666000	-1.369676000	-0.606856000
C	-1.171329000	-1.099433000	-0.686201000
C	-2.038289000	-2.056050000	-1.197130000
C	0.852424000	-0.197955000	-0.018820000
O	2.206846000	-0.168555000	0.129309000
C	-1.384545000	0.272344000	-0.170915000
C	-2.524377000	1.002376000	-0.173683000
C	-0.062792000	0.773549000	0.267356000
C	0.202848000	2.094993000	0.857581000
C	-0.554075000	2.687479000	1.797096000
C	2.798207000	0.102799000	1.365536000
H	-3.103033000	-1.878169000	-1.266608000
H	-2.170181000	-4.035703000	-2.025230000
H	1.807124000	-2.768213000	-0.974014000
H	0.250077000	-4.489206000	-1.890120000
H	-0.302416000	3.668597000	2.178118000
H	-2.512327000	2.028310000	0.174952000
H	-1.415393000	2.187604000	2.219957000
O	2.164249000	0.201119000	2.372986000
C	4.279711000	0.241263000	1.192676000
H	4.674656000	-0.570003000	0.579541000
H	4.480803000	1.182181000	0.672996000
H	4.757672000	0.253630000	2.169773000
C	-3.782188000	0.538553000	-0.631942000
N	-4.828510000	0.196901000	-0.990457000
C	1.378059000	2.782388000	0.390807000
N	2.336426000	3.309682000	0.018896000

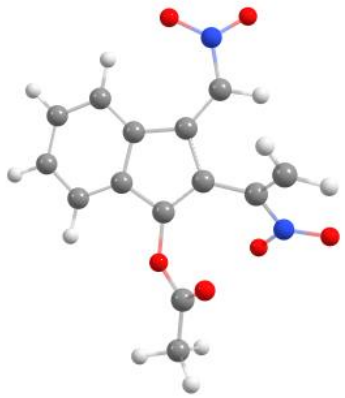


Figure S21: Allene substituted (R1: NO_2 and R2: NO_2) computed structure.

opt freq Ub3lyp/6-311+G(d,p) nosymm int=(grid=ultrafine)

SCF Done =	-1100.42674679
Zero-point correction =	0.224657 (Hartree/Particle)
Thermal correction to Energy =	0.244042
Thermal correction to Enthalpy =	0.244986
Thermal correction to Gibbs Free Energy =	0.174556
Sum of electronic and zero-point Energies =	-1100.202089
Sum of electronic and thermal Energies =	-1100.182705
Sum of electronic and thermal Enthalpies =	-1100.181761
Sum of electronic and thermal Free Energies =	-1100.252191

32

C	-1.461815000	-3.496683000	-1.777926000
C	-0.116362000	-3.818580000	-1.626502000
C	0.764669000	-2.909870000	-1.029732000
C	0.256383000	-1.694324000	-0.602743000
C	-1.104312000	-1.352884000	-0.750945000
C	-1.971880000	-2.265694000	-1.341224000
C	0.942145000	-0.583377000	0.052107000
O	2.275707000	-0.720991000	0.247425000
C	-1.258913000	0.027706000	-0.222886000
C	-2.274569000	0.917480000	-0.242661000
C	0.075279000	0.442257000	0.299836000
C	0.303993000	1.743548000	0.933576000
C	-0.360484000	2.249507000	1.969718000
C	2.959936000	-0.144238000	1.311977000
H	-3.021649000	-2.046726000	-1.450694000
H	-2.135875000	-4.209639000	-2.238048000
H	1.815373000	-3.142796000	-0.909174000
H	0.251914000	-4.777687000	-1.971763000
H	-0.135155000	3.239606000	2.341057000
H	-2.138940000	1.942623000	0.063982000

H	-1.120924000	1.662263000	2.466996000
O	2.401014000	0.330839000	2.255893000
C	4.435653000	-0.243977000	1.076050000
H	4.706658000	0.440895000	0.267965000
H	4.967001000	0.031756000	1.984234000
H	4.707883000	-1.252853000	0.761979000
N	1.386114000	2.607684000	0.344195000
O	2.106579000	2.090578000	-0.501312000
O	1.495552000	3.754689000	0.743597000
N	-3.618866000	0.723432000	-0.741100000
O	-4.123772000	-0.395897000	-0.739968000
O	-4.192861000	1.745008000	-1.111985000

6. References

[1] A. D. Becke, *J. Chem. Phys.* **1993**, *98*, 5648–5652.
[2] C. Lee, W. Yang, R. G. Parr, *Phys. Rev. B* **1988**, *37*, 785–789.
[3] M. K. Waddell, T. Bekele, M. A. Lipton, *J. Org. Chem.* **2006**, *71*, 8372–8377.
[4] M. Schmittel, C. Vavilala, M. E. Cinar, *J. Phys. Org. Chem.* **2012**, *25*, 182–197.
[5] S. Grimme, *J. Chem. Phys.* **2003**, *118*, 9095–9102.
[6] C. Riplinger, B. Sandhoefer, A. Hansen, F. Neese, *J. Chem. Phys.* **2013**, *139*, 134101.
[7] A. P. Scott, L. Radom, *J. Phys. Chem.* **1996**, *100*, 16502–16513.
[8] C. Gonzalez, H. B. Schlegel, *J. Phys. Chem.* **1990**, *94*, 5523–5527.
[9] H. P. Hratchian, H. B. Schlegel, *J. Chem. Phys.* **2004**, *120*, 9918–9924.
[10] H. P. Hratchian, H. B. Schlegel, *J. Chem. Theory Comput.* **2005**, *1*, 61–69.
[11] H. Frisch, MJ Trucks, GW and Schlegel, HB and Scuseria, GE and Robb, MA and Cheeseman, JR and Scalmani, G and Barone, V and Petersson, GA and Nakatsuji, *Gaussian Inc., Wallingford CT* **2016**, DOI 111.
[12] F. Neese, *Wiley Interdiscip. Rev. Comput. Mol. Sci.* **2012**, *2*, 73–78.
[13] G. Zhurko, D. Zhurko, "ChemCraft, Version 1.8," can be found under http://www.chemcraftprog.com, **2017**.
[14] C. Legault, "CYLview , Version 1.0b http://www.cylview.org," **2009**.
[15] P. J. Stephens, F. J. Devlin, C. F. Chabalowski, M. J. Frisch, *J. Phys. Chem.* **1994**, *98*, 11623–11627.
[16] Y. Zhao, D. G. Truhlar, *Theor. Chem. Acc.* **2008**, *120*, 215–241.
[17] Y.-S. Lin, G.-D. Li, S.-P. Mao, J.-D. Chai, *J. Chem. Theory Comput.* **2013**, *9*, 263–272.
[18] P. Jaque, A. Toro-Labbé, P. Politzer, P. Geerlings, *Chem. Phys. Lett.* **2008**, *456*, 135–140.
[19] P. Politzer, J. S. Murray, P. Jaque, *J. Mol. Model.* **2013**, *19*, 4111–4118.
[20] A. Toro-Labbé, *J. Phys. Chem. A* **1999**, *103*, 4398.
[21] P. Politzer, J. R. Reimers, J. S. Murray, A. Toro-Labbé, *J. Phys. Chem. Lett.* **2010**, *1*, 2858.